



## **Precontractual Investment and Modes of Procurement**

Alessandro De Chiara  
SBS-EM, ECARES, Université libre de Bruxelles and FNRS

June 2015

**ECARES working paper 2015-24**

# Precontractual Investment and Modes of Procurement<sup>\*</sup>

Alessandro De Chiara<sup>†</sup>

June 18, 2015

## Abstract

We study a repeated game in which a buyer must decide whether to procure goods whose design may turn out to be defective through auctions or negotiations. To reduce the likelihood of failure, the buyer must motivate the potential suppliers to make an investment before the contract is signed. As the noisy signal of the supplier's investment is non-verifiable, the buyer can induce the suppliers to invest only through relational contracts, that is informal agreements sustained by the parties' concern about the future. We find that auctions may not enable the buyer to implement a surplus-increasing relational contract even when the players are very patient. Therefore, negotiations may be adopted since they are more effective in stimulating the supplier's investment. We also show how the possibility of inducing the supplier's investment as well as the choice of the procurement mode affect the buyer's initial specification of the good. Moreover, we find that relational contracting may be valuable even when a design failure can be verified by a court. Finally, we highlight how our model is able to reconcile several real-world procurement practices.

Keywords: Auctions, Design Failure, Negotiations, Precontractual Investment, Private Procurement, Relational Contracts.

---

<sup>\*</sup>I am particularly grateful to Robert Gibbons and Patrick Legros for their insightful comments and suggestions. I also thank Tommaso Aquilante, Daniel Barron, Antonio Estache, Mate Fodor, Mark Hou, Elisabetta Iossa, Georg Kirchsteiger, Luca Livio, Ester Manna, David Martimort, Martin Peitz, Tom Potoms, Konrad Stahl and André Stenzel for helpful discussions. Thanks to audiences at University of Cologne, Central European University, Diego Portales University, XXXIX Simposio of the Spanish Economic Association in Palma de Mallorca, Universitat de Barcelona, University of Mannheim, ECARES, and MIT Organizational Economics lunch, where I presented an early version of this manuscript. Usual disclaimer applies.

<sup>†</sup>Université libre de Bruxelles (ECARES) and FNRS; aledechiara@gmail.com.

# 1 Introduction

Procuring a good whose design turns out to be defective can be extremely costly. This is especially so if the procurer is not the final user of the good. Consider, for instance, all the problems Boeing has experienced with the failure in the design of its new 787 Dreamliner. In January 2013, after two distinct cases of overheating involving the lithium-ion batteries, the planes had been grounded by the authorities. These batteries were one of the components Boeing had procured from its suppliers. The aircrafts were allowed to fly only several months later, when the causes of the problems were fixed.<sup>1</sup>

Adjusting the design of a good ex-post may thus have dire consequences: recalls, delays, the need to undo some works or redesign some other components, the possibility of disputes, the loss of reputation with customers.<sup>2</sup> To reduce the probability of having a defective design, the procurer of a sophisticated good, such as a building or a car's or an aircraft's part or component, may seek the involvement of the supplier at the planning stage. The supplier's know-how and skills can indeed be crucial to improve the initial design of the good provided by the buyer. A crucial issue is that the supplier's involvement often requires a costly precontractual investment for it may entail a careful inspection of all the details of the project as well as the development of prototypes or technical drawings.

The purpose of this paper is to investigate the buyer's choice of the procurement mode when there is uncertainty about the suitability of the design of the good. We show that the horizon of the relationship affects the buyer's choices of auctions versus negotiations and of the delegation of the design to the suppliers. In particular, when the interaction between the parties is repeated, negotiations are preferred and the design of the good is delegated to the suppliers. In contrast, when the interaction is one-shot, auctions are preferred and the design task is retained by the buyer.

We consider a repeated game in which a buyer selects a supplier to produce a good in each period. There is ex-ante uncertainty as to whether or not the design of the good will turn out to be correct. Initially we assume that only the suppliers can provide the technical drawings (or develop a prototype) for the good the buyer wants to procure. Each solicited supplier independently decides how much to invest in developing their own technical drawings. The technical drawings improve the design of the good and reduce the likelihood of failure if the selected supplier's investment has been high. The investment choice is private and is made before a supplier knows exactly how much it would cost him to produce that specific good. The suppliers differ with respect to the production costs which also vary over time. Their cost of production is private knowledge which makes it valuable for the buyer to screen the potential suppliers in every period. The buyer chooses the award mechanism, i.e. auctions or negotiations,

---

<sup>1</sup>The potential penalties for late deliveries that Boeing could be asked to pay to its customers will increase the already higher than anticipated cost that the development of the new wide-body jet has brought about. Boeing initially planned to spend around \$5 billion, but conservative estimates made by Barclays Capital say that the program will end up costing around \$14 billion. See "*The Two Men Behind the 787*", in *The Wall Street Journal*, January 24, 2013.

<sup>2</sup>The faults that have plagued the development and the delivery of the 787 may have cost Boeing its dominance in the Japanese aviation industry. See "*Turning Japanese*", *The Economist*, October 12, 2013.

and decides whether or not to bear the production cost. In an auction at least two firms bid on the price to produce the good according to their own technical drawings, whereas in a negotiation only one firm is solicited to develop the technical drawings.

We assume that each supplier's investment is project-specific, which leads to the well-known hold-up problem (see Klein et al., 1978 and Williamson, 1975), and the value of a supplier's contribution cannot be assessed in a court-enforceable contract.<sup>3</sup> In this environment only repeated interaction can create the conditions for the suppliers to undertake the investment, whereas formal incentives are ineffective. Repeated interaction allows the use of *relational contracts*, namely informal agreements that can be sustained by the parties' concern about the future.

When the interaction between the buyer and the suppliers is not repeated, the buyer anticipates that she will not receive any insight from the suppliers. The buyer will then focus on minimizing the cost of production. To this end, she will procure the good through an open auction, that is an auction in which all the potential suppliers in the market are solicited to submit a bid, and the selected supplier will be required to bear the production cost.

When the interaction is repeated, we find that negotiations are more effective than auctions in stimulating the investment. Auctions are ineffective in inducing the suppliers to invest since an essential feature of competitive bidding is that any reward promised by the buyer for delivering a flawless design is competed away at the bidding stage. Therefore, a supplier may be willing to invest only if the expected value of the information rent, which is all he can expect to obtain if he wins the auction, is larger than the investment cost. We call this condition the *bidding-competition* constraint. Furthermore, auctions augmented with relational contracts suffer from a severe credibility problem. This occurs because they may require an excessively expensive reward that the buyer may not credibly promise to pay. Consider that even if the value of the expected informal payment is incorporated in the bids, the buyer must promise a reward for a successful design so as to avoid that the potential suppliers decide to remain idle. The reward can be particularly high in auctions for two reasons. First, when a supplier invests there is uncertainty as to whether or not he will be awarded the contract. Second, by remaining idle a supplier obtains a positive payoff, whose size is inversely related to that of the reward itself. Inviting fewer bidders may not generate enough rents to prompt the investments and, as a result, the buyer may find it profitable to relinquish the benefits of auctions and directly negotiate with one supplier. Negotiations augmented with relational contracts do not require the bidding-competition constraint and need a lower reward to induce the investment, since the supplier must just receive the standard moral-hazard rent. When augmented negotiations are used, the buyer bears the production cost.

When we allow the buyer to provide the technical drawings of the good herself, she will prefer to retain the design task and delegate only the production of the good to the suppliers when the interaction is not repeated. In contrast, the buyer may be better off delegating the design of the good to the suppliers when the interaction is repeated, for they can be motivated to invest. As a result, the model provides some important predictions about firms' procurement

---

<sup>3</sup>Even ex-post, it is often difficult for a court to determine whether the good meets all the buyer's desired specifications and who is to blame for a design failure. In the Boeing 787 case, the cause of the battery failure has never been determined.

practices in the private sector. It suggests that we should observe that buyers use open auctions when they entirely develop the design of the good in-house while they use restricted auctions and direct negotiations when they delegate the design of the good to their suppliers.

The paper can help reconcile a number of findings in the management literature concerning buyer-supplier relationships. It seems particularly suitable to account for the sharp differences between the supply-chain practices in the Japanese and the U.S. manufacturing industry in the early 1980s and the subsequent adoption of Japanese-style procurement practices in the U.S.. In particular, American car manufacturers used to develop the specification of the good entirely by themselves and select suppliers through open bidding. In doing so, they hardly received any ideas from the suppliers on how to improve the design of the car parts or components. In contrast, Japanese car manufacturers delegate the design of the good to their suppliers, who are selected through auctions with a limited number of firms in which the incumbent is strongly favored, so that the selection procedure closely resembles a negotiation. The increasing technical complexity of vehicles as well as the proliferation of car models led U.S. assemblers to embrace Japanese-style procurement practices in the second half of the 1980s. The predictions of our model also appear to be consistent with the procurement practices adopted in other industries, such as sophisticated electronics (Burt, 1989) and construction industry (Bajari et al., 2009). In the latter case, the authors find that more complex projects, for which the suppliers' insight is more valuable, are procured through negotiations or restricted auctions.

## 1.1 Related Literature

Our paper is part of the burgeoning literature on relational contracts whose foundations have been laid by Bull (1987), MacLeod and Malcomson (1989), Baker et al. (1994), and Levin (2003) (see Malcomson, 2012, for a recent survey). In the paper we use the well-known result of Levin (2003) on the optimality of stationary contracts. This author shows that present compensation and future payoffs are substitutable instruments to provide incentives when the parties are risk neutral and the performance measure is observed by both the principal and the agent. In this case, an incentive scheme that uses continuation payoffs to reward/punish the agent may be replicated by a scheme only based on immediate compensation. As a result, in searching for optimal contracts, it suffices to focus on contracts which are stationary, namely that involve the same compensation schedule and the same effort in every period.

Recently, several papers have analyzed the use of relational contracts in procurement. Corts (2012) compares two widely used contractual forms in construction and procurement contracting, fixed-price and cost-plus contracts. The former provides efficient cost-minimization incentives but is costly to renegotiate while the latter does not give any incentive to reduce costs but its flexibility comes in handy when design changes must be implemented. In a repeated setting, Corts finds that the buyer is more likely to prefer cost-plus contracts. This is because the buyer can take full advantage of the strength of informal incentives only if the contract is drawn in an (augmented) cost-plus fashion as this prompts the agent to exert effort in every period, whereas in an (augmented) fixed-price contract the probability that the informal contract will be used to accommodate some modifications is not necessarily equal to 1 since renegotiation may not be

needed. This article does not investigate how the supplier is selected and how the contracting parties can affect the probability that a design change is needed.

Tunca and Zenios (2006) consider head-to-head competition between two alternative procurement modes: auction (in the electronic marketplace) and a relational contract with a long-term trading partner. The former is efficient when the quality features of the components procured are not relevant as it ensures the selection of the low-cost bidder. The latter is adopted to procure parts whose quality aspects are both non-verifiable and valuable. In their model, there is only one high-quality supplier who can decide whether to supply a high or a low quality good to the manufacturers. If he cheats, the manufacturers will retaliate by procuring parts from the auction market thereafter. The authors show under what conditions the two procurement modes can coexist and find that competition from the auction market can either facilitate or undermine the sustainability of the relational contract.

Andrews and Barron (2013) develop a repeated moral-hazard problem between one buyer and many suppliers in the presence of imperfect private monitoring and in which each supplier may not be able to produce in every period. They find that the buyer rewards a supplier who performs well with additional contracts (i.e. success is rewarded) and that this favored supplier loses future business only if, in a period in which he cannot produce, the replacement performs well (i.e. failure is tolerated).

Board (2011) analyzes a principal who must invest in one of many suppliers in each period. He shows that relational contracts can mitigate the hold-up problem and induce loyalty, in the sense that those trading parties with whom the principal has dealt in the past will be favored over the outsiders when new contracts are awarded. The role of the award mechanism is not examined and it is assumed that the principal cannot extract the suppliers' expected rents.

Calzolari and Spagnolo (2009) study the procurement mode chosen by the buyer in a repeated setting. Like us, they find that the buyer may be willing to restrict competition but the underlying reason is sharply different. In their model the supplier chooses the observable but non-verifiable quality of the good (no hidden-action) and the relational contract is enforced by bilateral punishments, i.e. if the relationship between the buyer and one supplier falls apart, the other suppliers do not observe the identity of the deviator. This latter assumption critically limits the punishment the buyer faces following a deviation and this ultimately leads to a restriction in the number of suppliers to achieve the desired level of quality.

We depart from this literature by analyzing an ex-ante moral-hazard problem in which there is a non-observable project-specific investment to be made *before* the contract is awarded and there is a non-verifiable noisy signal of performance.<sup>4</sup>

While they do not study the incentive role of relational contracting, Loertscher and Riordan (2014) develop a model similar to ours. Suppliers must make a non-contractible investment in designing a good for a buyer before knowing with certainty their cost of production. They assume that the precontractual investment shifts the supplier's cost distribution downwards in the sense of first-order stochastic dominance, whereas we consider a supplier's investment which

---

<sup>4</sup>A noteworthy exception is Calzolari et al. (2014). However, their main aim is to study empirically the interaction between trust, competition and investment using survey data on individual buyer-supplier relationships in the German automotive industry.

increases the buyer's expected return from the project.

Our paper is also related to the research tournament literature initiated by Taylor (1995). In a research tournament a sponsor invites a number of contestants to innovate and then selects and rewards the contestant with the best innovation on a predetermined date. This literature shows that research contests promote innovation when the outcome is observable but not verifiable in court and that it may be desirable to restrict competition to stimulate the contestants' effort. In contrast, a negotiation would not provide any incentive to innovate.<sup>5</sup> Considering a repeated interaction environment in which the outcome is not observable ex-ante we show that negotiations can stimulate innovation and may in fact dominate research contests because they entail a lower cost of providing incentives.

Finally, we also investigate the interplay between the procurement mode and the buyer's initial investment in the design of the good, which is a dimension that has not been analyzed in the above papers. In developing a model of endogenous design incompleteness, we draw on Bajari and Tadelis (2001) who were the first to put forward the idea of an initial investment into planning which reduces the likelihood that the design of the good fails. They study a one-shot procurement game between a buyer and a seller and highlight the tension between ex-ante cost-reduction incentives, which call for a high-powered incentive scheme (i.e. a fixed-price contract), and ex-post transaction costs, which call for a low-powered incentive scheme (i.e. a cost-plus contract). They find that buyers should make use of cost-plus contracts when projects are more complex, namely when there is a higher probability that the design of the good fails. They do not allow for a (partial) delegation of the design to the supplier and do not focus on potential heterogeneities among different suppliers.

The remainder of the paper proceeds as follows. In the next section we set up the model. In Section 3 we show that in the absence of repeated interaction, the buyer cannot motivate the suppliers to invest. In this setting, we find that the buyer optimally solicits bids from all  $N$  available suppliers, that is she uses an *unrestricted auction* to procure a good. In Section 4 we explore augmented auctions and augmented negotiations, namely auctions and negotiations paired with relational contracts. We discuss how the results of our model may provide an explanation for the different procurement practices adopted in the manufacturing industry. In Section 5 we analyze several variants of the benchmark model developed in Section 4 to check the robustness of the main results and to provide additional insights. In Subsection 5.1 we extend the model to consider the buyer's investment in the initial specification of the good. We find that in the presence of repeated interaction the buyer's initial specification of the good will tend to be more incomplete so as to reduce the costs of incentives. In Subsection 5.2 we assume that a court can verify a design failure. We show that this may not solve the investment problem. In Subsection 5.3 we assume that the buyer is able to infer the suppliers' investment from observing the technical drawings. This allows us to understand the role played by moral-hazard in determining our results. In Section 6 we conclude.

---

<sup>5</sup>Other relevant papers in this literature include Fullerton and McAfee (1999), Moldovanu and Sela (2001), and Che and Gale (2003).

## 2 The Model

*Players.* We consider a risk-neutral buyer who, in each period  $t = 1, 2, 3, \dots$ , wants to procure a good from one of  $N \geq 2$  risk-neutral potential suppliers. The buyer is female while the suppliers, indexed by  $i \in \{1, \dots, N\}$ , are male. Buyer's and supplier  $i$ 's utility functions are denoted by  $u$  and  $\pi_i$ , respectively. The players discount future payoffs using the same discount factor  $\delta$  and the overall payoffs are multiplied by  $1 - \delta$  to obtain per-period averages. The buyer and the suppliers have outside options giving 0.

*Design Failure.* We assume that there is uncertainty as to whether or not the design of the good will turn out to be correct. The buyer derives utility  $v$  if the design is correct and  $v - k$  if it is flawed. The parameter  $k > 0$  is meant to capture both the loss of utility the buyer incurs if she markets a defective product, such as the loss of reputation and the penalties associated with delays, and the increased cost of producing the good, e.g. the cost of fixing the defective design. The probability with which the initial specification of the project is flawed is  $1 - \beta$ . We assume that  $\beta$  is known to all the players of the game and, for tractability reasons, it is the same for all the goods procured by the buyer.

*Supplier's investment.* In each period the buyer issues a request for business proposals. A proposal entails the development of the technical drawings of the good, which are essential for production.<sup>6</sup> The buyer solicits a subset of the suppliers  $\mathcal{N}_t \subseteq \{1, \dots, N\}$  to submit their business proposals. We denote by  $n_t$  the cardinality of  $\mathcal{N}_t$ ,  $n_t \equiv |\mathcal{N}_t|$ . The buyer will then select one of the invited suppliers to produce the good according to his own drawings. Each supplier independently and privately decides how much to invest in preparing their proposal. We assume that this investment is binary, i.e.  $e_i \in \{0, 1\}$ . The cost of the investment is  $ge_i$ , with  $g > 0$ . The technical drawings supplier  $i$  can provide at time  $t$  are *superior* if  $e_{it} = 1$  and *standard* if  $e_{it} = 0$ . While standard drawings do not affect the probability of an ex-post failure, superior drawings reduce it to  $(1 - \beta)(1 - \rho)$ . Thus,  $\rho \in (0, 1)$  captures the probability that superior drawings correct existing flaws in the initial specification of the good. We assume that the buyer cannot detect whether  $e_{i,t} = 0$  or  $e_{i,t} = 1$  from observing  $i$ 's proposal. This implies that a supplier could pretend that his standard drawings are in fact efficiency enhancing without incurring any cost and the buyer would not be able to distinguish them from ones which are effectively superior. Throughout we assume that it is efficient that a supplier undertakes the investment.

**Assumption 1.** *The following condition holds:*

$$(1 - \beta)\rho k > g.$$

The above inequality says that the benefits of superior technical drawings, namely the reduction in the probability that the buyer incurs the loss of utility due to a design failure, outweigh the investment cost.

---

<sup>6</sup>Instead of the technical drawings, one may think of the buyer asking the potential suppliers to develop a prototype of the good.



*Cost of production.* We assume that only after investing a supplier learns exactly how much it would cost him to produce the good according to his own drawings,  $c_{it}$ . Before investing, a supplier only knows the cost distribution. This can be due to the great uncertainty about the costs of production that suppliers face before examining the details of a project and developing the technical drawings. In construction procurement, for instance, sources cited by Bajari and Tadelis (2001, page 390) maintain that reasonable cost targets can be established only when project engineering is 40% – 60% complete.<sup>7</sup> We assume that  $c_{it}$  is independently and identically distributed according to the continuous distribution  $\Phi(c)$ , with density  $\phi(c)$ , on the interval  $[\underline{c}, \bar{c}] \subset \mathbb{R}_+$ , with  $\bar{c} > \underline{c}$ . While the cost distribution is publicly known, a supplier is privately informed about his own cost of production. The assumption that the production cost is project-specific can be justified by the wide variety of goods that a buyer typically procures, each with their own specific features.<sup>8</sup> Moreover, we assume that  $v - k \geq \bar{c}$  so that it is socially efficient to produce the good, even when the probability of a design failure is one.

*Non-verifiability of the design failure.* We assume that a design failure is observed by all the players of the game but that a court-enforceable contract contingent on this event cannot be written. Problems occurring after the production of the good may cause delays and disputes and, as a result, are difficult to conceal. At the same time, it may be difficult for a court to assess whether the good produced is not exactly as conceived by the contracting parties or whether either of them is claiming the presence of non-existing flaws. Consistently, we also assume that the buyer's payoff is observable but non-verifiable. In Section 5 we assume that a court can observe whether a design failure has occurred and we show that the main results of our model on the role of relational contracts are preserved.

*The choice of the procurement mode.* At the beginning of each period, the buyer chooses how many suppliers to invite to develop the drawings of the good and the contractual form. Moreover, she can set a participation fee  $f_t \in \mathbb{R}$  that a solicited supplier must pay to see the details of the project. We focus on two polar contractual forms: fixed-price and cost-plus contracts. If the contract is written in a *fixed-price fashion*, the selected supplier must bear the entire cost of production. In contrast, if the contract is written in a *cost-plus fashion*, the buyer is required to cover the entire cost of production. The restriction on these two contractual forms is made to simplify exposition and is inconsequential for the buyer's ability to extract the suppliers' expected surplus as she can use the participation fee.<sup>9</sup> We distinguish between two polar

---

<sup>7</sup>We may also assume that the type of drawings supplied can affect the cost of production. For instance, supplier  $i$ 's cost of production may be augmented by an additive parameter  $\epsilon_{i,t}e_{it}$  with mean  $\mu_\epsilon = 0$  and small variance. This would not change the results of the analysis.

<sup>8</sup>In construction procurement, the specificities of a project are related to the location, the size (e.g. the number of stories in a building), the type of material to be used. In manufacturing, the characteristics of the components and the parts that assemblers procure vary from one good to another. For instance, in the automotive industry, the chassis, the engine, or the brakes are markedly different depending on the model (e.g. a city-car, a sedan, or a sports car).

<sup>9</sup>These two extreme contractual forms are also the most widely used in construction procurement (see Bajari and Tadelis, 2001).

award mechanisms, direct negotiations and auctions. In an *auction*,  $n \geq 2$  suppliers are solicited to submit a price bid  $b$ . The contract is awarded to the lowest bidder, and we assume that a second-price reverse auction is held and, as a result, the selected supplier receives the value of the second lowest bid once production is complete.<sup>10</sup> Under a *direct negotiation* the buyer asks a single supplier to present the technical drawings. The bids as well as the supplier's choice of trade are publicly observed.

*Timing.* In every period, the timing of the game is as follows:

- At stage 1, the buyer announces the procurement mode and sets the participation fee.
- At stage 2, the suppliers who have been solicited to submit the proposal and have accepted to participate independently decide whether or not to incur the investment cost.
- At stage 3, each supplier learns his own cost of production  $c_{i,t}$ .
- At stage 4, the buyer signs the contract according to the rules of the chosen procurement mode. The buyer's choice of the supplier is public and denoted by  $q_t = \{q_{i,t}\}_{i=1}^N$ , with  $q_{i,t} \in \{0, 1\}$ , and  $\sum_{i=1}^N q_{i,t} \leq 1$ .
- At stage 5, the good is produced at a verifiable cost  $c_t = \sum_{i=1}^N q_{i,t} c_{i,t}$ .
- At stage 6, uncertainty is resolved and payoffs are realized.

### 3 One-time Procurement

We begin by analyzing the procurement mode the buyer adopts in the absence of repetition. First note that in the one stage game the suppliers' investment to provide superior drawings of the good cannot be encouraged, irrespective of the chosen procurement mode. This is because the design failure is non-verifiable and the cost a supplier bears in preparing his own proposal is sunk.

In a one-shot auction, the buyer's expected utility is given by:

$$u^{auc} = v - (1 - \beta)k - EP(b) - \gamma E(c_w) + \sum_{i \in \mathcal{N}} f_i$$

where  $\gamma \in \{0, 1\}$  denotes the fraction of costs of the selected supplier, indexed by  $w$ , which is covered by the buyer and  $EP(b)$  denotes the expected payment made to the winning bidder and is a function of the bids. In a second-price auction  $EP(b)$  is equal to the value of the second-smallest bid. Let us define  $c_m^n$  as the expected value of the  $m$ -th highest order statistic

---

<sup>10</sup>Most of the results of the analysis would not change if the buyer held a first-price reverse auction as the conditions of the Revenue-Equivalence Theorem are satisfied, i.e., bidders are risk-neutral and their types are independently and identically distributed (see Myerson, 1981). We consider second-price auctions in the analysis for tractability reasons. Moreover, note that the buyer only evaluates price bids since she is unable to appraise the technical drawings properly.

of  $n$  draws from the distribution  $\Phi$  on  $[\underline{c}, \bar{c}]$ .<sup>11</sup> We now formally define the *expected information rent* which plays a crucial role throughout the analysis.

**Definition 1.** *The expected information rent accruing to a supplier in an auction with  $n$  bidders is:*

$$\frac{1}{n}I(n) \equiv \frac{1}{n}(c_{n-1}^n - c_n^n)$$

The expected information rent is given by the product of the ex-ante probability of winning the auction, which is  $\frac{1}{n}$  as the suppliers are ex-ante identical, and the expected gain from winning the auction when the contract is fixed-price, which is the difference between the two smallest order statistics,  $c_{n-1}^n - c_n^n$ .

In an auction, the buyer maximizes her utility by choosing the contractual form, the participation fee and the number of bidders. In the following lemma we determine the buyer's expected utility from holding an auction to procure a good:

**Lemma 1.** *In a one-shot auction  $\gamma = 0$ ,  $EP(b) = c_{n-1}^n$ , the buyer sets  $f_i^{auc} = f^{auc} = \frac{1}{n}I(n)$  for all  $i \in \mathcal{N}$  and solicits bids from  $N$  suppliers.*

*The buyer's expected utility from procuring a good through an auction is given by:*

$$u^{auc} = v - (1 - \beta)k - c_N^N \quad (1)$$

*Proof.* In the appendix. □

In a second-price reverse auction, the buyer uses a fixed-price contract to ensure that the bids will reflect the suppliers' costs of production.<sup>12</sup> The lowest cost supplier is awarded the contract and receives a price equal to the second lowest bid, which in expectation is  $c_{n-1}^n$ . The buyer optimally sets a participation fee  $f^{auc} = \frac{1}{n}I(n)$  to guarantee the suppliers' participation in the auction and fully extract their expected information rent. Finally, as the buyer's expected utility is increasing in the number of bidders, the buyer holds an *unrestricted or open auction*, that is  $n^{auc} = N$ .

If the buyer procures a good through a negotiation, the supplier is selected randomly and his expected cost of production is  $E(c)$ . By writing the contract in a cost-plus fashion, the buyer's expected utility is:

$$u^{neg} = v - (1 - \beta)k - E(c) \quad (2)$$

The supplier does not earn any rent and therefore  $f^{neg} = 0$ . Note that the buyer cannot gain from writing the contract in a fixed-price fashion as the supplier would ask a price at least equal to his cost of production, which in expectation is  $E(c)$ .

Comparing (1) and (2) it is straightforward to see that in the one-shot game auctions outperform negotiations: while the former always select the least-cost supplier, the latter do so with

---

<sup>11</sup>In defining the order statistics, we follow the auction theory literature which customarily rearranges the draws from the highest to the lowest, in contrast to the statistic notation and terminology which conventionally rearranges the draws from the smallest to the highest.

<sup>12</sup>This is consistent with the standard procedure followed in construction procurement. As a reference, consider that the standard cost-plus contract provided by The American Institute of Architects, the A-102-2007, is not intended for use in competitive bidding.

probability  $\frac{1}{N}$ . Therefore (1) represents the outcome to which the buyer will revert if she fails to sustain an efficiency-enhancing informal agreement in the repeated game.

## 4 Repeated Interaction and the Use of Relational Contracts in Procurement

We now consider the infinitely repeated version of the buyer's problem. Repeated interaction enables the buyer to use informal incentives to induce the desired action from the suppliers provided that the punishment each party faces if they defect is severe enough.

In our setting the buyer might be able to induce the supplier's investment by promising different payoffs following the resolution of uncertainty at stage 6. In particular, the seller can be rewarded if the design of the good turns out to be correct and punished otherwise. Formally, the stage game of the previous section is enriched in the following way. In every period  $t$  the buyer agrees to pay the selected supplier a discretionary reward  $r$ , contingent on the realization of  $\xi \in \{S, F\}$  at stage 6 where  $\xi = F$  if the design fails and  $\xi = S$  if it "succeeds".

To describe the informal contracts that govern the relationship between the buyer and the set of  $N$  potential suppliers we follow the literature on relational contracts, and more specifically Levin (2003). There is a collection of  $N$  relational contracts each describing a complete plan for the bilateral relationships between the buyer and one supplier. For any period  $t + \tau$ , with  $\tau = 0, 1, 2, \dots$  the relational contract  $i$  specifies the offer made by the buyer to supplier  $i$ ,  $q_{i,t+\tau}r_{i,t+\tau}$ , contingent on the realization of  $\xi_{t+\tau}$ . The relational contract also prescribes parties' behavior if either of them deviates, namely if either the buyer refuses to pay or the supplier refuses to accept the contingent reward. Crucially, we assume that market participants are able to identify which party has defected.

We analyze the use of relational contracts in augmented auctions and augmented negotiations separately and we then determine the procurement mode the buyer prefers.

### 4.1 Augmented Auctions

Suppose that the buyer wants to hold an auction in every period to select the supplier and wishes to employ informal incentives to complement the formal contract so as to improve upon the outcome of the stage game. Specifically, the buyer holds *augmented auctions* wherein she uses contingent rewards to induce the investment.

Under augmented auctions, public history at time  $t$  is  $h_t = \{\mathcal{N}_t, f_t, \{b_{i,t}\}, q_t, c_t, \xi_t, \{q_{i,t}r_{i,t}\}\}$ . Public history up to  $t$  is  $h^t = \{h_1, \dots, h_{t-1}\}$ . For each player  $i \in \{1, \dots, N\}$  private history also contains information on  $i$ 's own investment decision,  $e_{i,t}$ , when  $i$  has been invited to submit a proposal, i.e. when  $i_t \in \mathcal{N}_t$ , for  $t = 1, 2, \dots$ . We can distinguish between the set of cooperative histories  $H^c$  in which the buyer has always followed through on her promises and the set of non-cooperative histories  $H^{nc}$  in which the buyer has cheated at least once.

As is standard in this literature, we say that the collection of  $N$  relational contracts is self-enforcing if it can be sustained by a Perfect Public Equilibrium (PPE) of the repeated game. A strategy is public if it depends only on public history, and not on a player's private history. A

PPE is a profile of public strategies that form a Nash Equilibrium from  $t$  onwards for any public history  $h^t$  (see Fudenberg et al., 1994).

We focus on symmetric pure-strategy equilibria and we consider trigger strategies in which the parties cooperate with each other until a deviation is observed.<sup>13</sup> Namely, the buyer always pays the promised rewards and the suppliers always undertake the investment and accept the buyer's rewards whenever they believe that the history is  $H^c$ , and never invest and never accept the buyer's promised rewards otherwise.

A deviation from the buyer is detected by all the players of the game, included those suppliers who have not been invited to submit their proposals in that period. The suppliers react by ceasing to trust the buyer's proposed non-enforceable rewards. The fact that relational contracts are sustained by a multilateral punishment seems to be realistic. Many procuring firms themselves promote suppliers' associations, which ease information sharing among market participants (for Toyota, among others see Roberts, 2004, pp. 204-206). As a result, if the buyer reneges, her reputation (goodwill) is tarnished and she can only use formal contracts in future periods (see Baker et al., 1994), in which case she cannot attain more than the static auction payoff. If the supplier deviates, the bilateral relationship ends with probability one and the buyer will optimally decide whether or not to blacklist the deviant supplier.<sup>14</sup>

Denote by  $R_t(e_{i,t})$  the expected value of the discretionary payment a winning supplier receives at time  $t$  if he has invested  $e_{i,t}$ .<sup>15</sup>

$$R_t(e_{i,t}) \equiv \begin{cases} [\beta + (1 - \beta)\rho]r_{t,\xi_t=S} + (1 - \beta)(1 - \rho)r_{t,\xi_t=F} & \text{if } e_{i,t} = 1 \\ \beta r_{t,\xi_t=S} + (1 - \beta)r_{t,\xi_t=F} & \text{if } e_{i,t} = 0 \end{cases}$$

Supplier  $i$ 's expected utility at time  $t$  is the following discounted sum of the stream of payoffs:

$$\pi_{i,t} = (1 - \delta)E \sum_{\tau=t}^{\infty} \delta^{\tau-t} \{ [P(b_\tau) - (1 - \gamma_\tau)c_{i,\tau} + R_\tau(e_{i,\tau})]q_{i,\tau}(b_\tau) - ge_{i,\tau} - f_{i,\tau} \} \mathbb{1}_{i,\tau} \quad (3)$$

where  $\mathbb{1}_{i,\tau} = 1$  if supplier  $i_\tau \in \mathcal{N}_\tau$ , that is if  $i$  is invited and accepts to participate in the auction at time  $\tau$  and  $\mathbb{1}_{i,\tau} = 0$  otherwise. The buyer's expected utility at time  $t$  is given by

$$u_t = (1 - \delta)E \sum_{i=1}^N \sum_{\tau=t}^{\infty} \delta^{\tau-t} \{ [v - (1 - \beta)(1 - \rho e_{i,\tau})k - P(b_\tau) - \gamma_\tau c_{i,\tau} - R_\tau(e_{i,\tau})]q_{i,\tau} + f_{i,\tau} \} \mathbb{1}_{i,\tau} \quad (4)$$

To simplify the analysis of optimal contracts, we can restrict attention to stationary contracts, namely contracts which prescribe the same reward offer, the same participation fee, the same contractual form, and the same number of solicited suppliers in every period. As a result,  $r_{t,\xi_t} = r_{\xi_t}$ ,  $f_t = f$ ,  $\gamma_t = \gamma$ , and  $n_t = n$  in every period  $t$ .<sup>16</sup>

<sup>13</sup>An analysis of symmetric mixed-strategy equilibria in which we show that the main results of our model continue to hold can be provided on request.

<sup>14</sup>The choice is not trivial only when  $n = N$  so that the buyer must decide whether to hold augmented auctions with  $N - 1$  suppliers or revert to auctions with  $N$  suppliers and no informal contracts. Conversely, if  $n < N$ , the buyer can costlessly replace the deviant supplier.

<sup>15</sup>As the suppliers are all identical with respect to their ability to deliver superior drawings, the buyer offers the same discretionary reward schedule to each seller she interacts with and therefore we can drop the index  $i$  at  $R_{i,t}$ .

<sup>16</sup>See Levin (2003, theorem 2).

Let  $SW^A(n)$  be the surplus that can be achieved in augmented auctions in which  $n$  suppliers are solicited to submit a proposal and which implement  $e_{i,t} = 1$  for each invited supplier  $i$  and  $t = 1, 2, \dots$ , namely:

$$SW^A(n) = v - (1 - \beta)(1 - \rho)k - ng - c_n^n \quad (5)$$

Note that the surplus maximizing number of solicited suppliers,  $n^*$ , is monotone nonincreasing in the investment cost  $g$ .<sup>17</sup> To achieve  $SW^A(n)$ , each supplier must prefer to invest rather than remain idle. Consider that in the investment stage the suppliers play a non-cooperative Nash game taking into account the bidding equilibrium. If the contract is written in a fixed-price fashion, in a second-price auction it is a weakly dominant strategy for each supplier  $i$  to bid his true production cost,  $c_{it}$ , minus the expected value of the discretionary payment he would receive if he wins the auction,  $R(e_{it})$ .

When each supplier invests,  $EP(b) = c_{n-1}^n - R(1)$ , which implies that the suppliers compete away at the bidding stage the expected value of the discretionary payment associated with  $e = 1$ . Therefore, at the investment stage, the only rent a supplier expects to obtain is the information rent associated with his private knowledge of his cost of production. Then, a necessary condition for a supplier to be willing to invest is that the expected information rent is large enough so as to compensate him for the investment cost. We call this condition the *bidding competition constraint* (BCC):

$$\pi_{it}(e_{it} = 1 | e_{-it} = 1) = \frac{1}{n}I(n) - g \geq 0 \quad (\text{BCC})$$

Augmented auctions with  $n$  bidders cannot induce each supplier to invest when the above constraint is not satisfied at that  $n$ . This is so even if they increase surplus relative to the static outcome. This stands in contrast to the rest of the literature in relational contracting in which surplus improving relational contracts can always be self-enforced when the players are patient enough.

Only if the (BCC) is satisfied, the buyer can motivate the suppliers to invest. To this end, the buyer must create a wedge between  $R(1)$  and  $R(0)$  so that a supplier who remains idle has a lower expected payoff. Provided that the (BCC) holds, it is always possible to set the differential  $R(1) - R(0)$  large enough so as to induce all the suppliers to invest. However, there is a credibility problem since a higher  $R(1) - R(0)$  translates into a higher reward that the suppliers must credibly expect the buyer to pay. For this reason, the buyer finds it profitable to choose the smallest such differential.<sup>18</sup> We define  $B(n, g)$  as the minimum differential  $R(1) - R(0)$  such that  $e_i = 1 \forall i \in \mathcal{N}$  is the only equilibrium in the investment stage. We can characterize the lower and the upper bounds of  $B(n, g)$ :<sup>19</sup>

$$g < B(n, g) \leq \max\{\bar{c} - \underline{c}, g + \frac{1}{n}I(n) + c_1^1 - c_{n-1}^{n-1}\}$$

<sup>17</sup>To see this, note that  $SW^A$  exhibits nondecreasing differences in  $(n, -g)$  and, as a result,  $n^*$  is monotone nonincreasing in  $g$ .

<sup>18</sup>Consider that the collection of relational contracts is self-enforcing only if, in addition to participation and incentive compatibility constraints, it satisfies suppliers' and buyer's dynamic enforcement constraints which ensure that neither the suppliers nor the buyer, respectively, are willing to back out on their promises. Thus, by setting the lowest rewards which satisfy the supplier's dynamic enforcement and incentive compatibility constraints, the buyer minimizes her maximum temptation to renege on the relational contracts.

<sup>19</sup>We defer the proof of these inequalities to the Appendix - see proof of Proposition 1.

$B(n, g)$  is always strictly larger than the investment cost  $g$ . This is because a supplier who invests is uncertain as to whether or not he will be awarded the contract. Moreover, by remaining idle a supplier can attain a positive payoff whose magnitude decreases as  $B(n, g)$  grows large. In addition, when the difference between the expected information rent and the investment cost is positive but small,  $B(n, g)$  must be very high to induce the investment.  $B(n, g)$  is equal to the maximum between  $(\bar{c} - \underline{c})$  and  $(g + \frac{1}{n}I(n) + c_1^1 - c_{n-1}^{n-1})$  when the difference between the expected information rent and the investment cost is zero. The former equality guarantees that a supplier is willing to invest when at least one rival supplier invests. The latter equality avoids an equilibrium in which each supplier remains idle.<sup>20</sup>

We can now determine under what conditions augmented auctions which generate  $SW^A(n)$  can be sustained.

**Proposition 1.** *Augmented auctions that obtain  $SW^A(n)$  and yield the buyer utility  $u^A(n)$  are self-enforcing if the (BCC) and the following buyer's dynamic enforcement constraint hold:*

$$\frac{\delta}{1-\delta} \underbrace{[(1-\beta)\rho k - ng - (c_n^n - c_N^N)]}_{u^A(n) - u^{auc}} \geq \frac{B(n, g)}{(1-\beta)\rho} \quad (BDE^A)$$

*Proof.* In the Appendix. □

When there is higher uncertainty about the suitability of the design of the goods the buyer procures, sustaining the relational contract is easier. There are two reasons why a lower  $\beta$  helps implement  $e = 1$  in augmented auctions. First, a supplier's investment is more valuable when there is a higher likelihood that the good is ex-ante defective, increasing the surplus generated by relational contracting. Second, the observation of  $\xi$  better informs the buyer about the supplier's investment when  $\beta$  is lower, thereby reducing the cost of providing incentives. Likewise, a higher  $\rho$  helps obtain  $e = 1$ . In contrast, a higher investment cost has a negative impact on the possibility of obtaining  $SW^A(n)$ . This is because a higher  $g$  makes it harder to satisfy the bidding-competition constraint, reduces the buyer's surplus from relational contracting, and increases the temptation to renege.

The buyer is better off writing a fixed-price contract,  $\gamma^A = 0$ , and sets the participation fee equal to the suppliers' expected information rent net of the investment cost, i.e.  $f^A = \frac{1}{n}I(n) - g$ . The buyer's expected utility in augmented auctions which obtain  $SW^A(n)$  is

$$u^A(n) = v - (1-\beta)(1-\rho)k - c_n^n - ng \quad (6)$$

If augmented auctions can be sustained at  $n^*$ , social and buyer's incentives are perfectly aligned. The buyer may find it profitable to solicit bids from a number of bidders lower than  $n^*$  only

---

<sup>20</sup>When the expected surplus is zero, i.e.  $\frac{1}{n}I(n) = g$ , a supplier is willing to invest when his  $n-1$  rivals are investing only if also what he expects to earn by remaining idle is zero. This requires that that supplier does not stand a chance of winning the contract if  $e = 0$ , namely  $\bar{c} - R(1) \leq \underline{c} - R(0)$ , or  $R(1) - R(0) \geq \bar{c} - \underline{c}$ . This also ensures that a supplier is willing to invest when at least one rival is investing. However, the buyer must also avoid that  $e_i = 0$  for each  $i \in \mathcal{N}$  constitutes an equilibrium, and setting  $R(1) - R(0) = \bar{c} - \underline{c}$  may not suffice. To see this, consider that a supplier is willing to invest when everyone else remains idle only when  $R(1) - R(0)$  reimburses him of at least the opportunity cost,  $\frac{1}{n}I(n)$ , the cost of investment  $g$ , and the cost differential between his expected cost and the smallest expected cost of his rivals,  $c_1^1 - c_{n-1}^{n-1}$ .

if this is necessary to sustain the relational contracts. However there are limits to the buyer's ability to use this instrument to induce the suppliers' investment in an auction environment as moving away from  $n^*$  gives rise to a tension between the bidding-competition and the reneging constraint. Specifically, restricting competition may be helpful to sustain  $e = 1$  in augmented auctions thanks to its positive effect on the bidding competition constraint. Competing with fewer rivals increases the probability of being the lowest cost bidder as well as the magnitude of the information rent. Restricting competition may have negative effects on the buyer's dynamic enforcement constraint, though, since it decreases the surplus of relational contracting.

## 4.2 Augmented Negotiations

Augmented auctions suffer from two main drawbacks. First,  $e = 1$  can be attained only if the expected information rent is higher than the investment cost. Second, there is a severe credibility problem as the magnitude of the reward the buyer must promise in case of a success may need to be excessively large. Restricting competition may not be an effective means to approach these problems as it may fail to generate information rents sufficiently large relative to the investment cost.

The two drawbacks mentioned above are ultimately caused by an essential feature of competitive bidding, namely bidders compete away the expected rewards at the bidding stage. Therefore, when competition for the contract prevents investment, moving away from auctions may be a viable alternative. Since in a direct negotiation the expected discretionary payment  $R(e_i)$  is not incorporated in a bid, the buyer can always promise the supplier a reward scheme which induces the investment. Moreover, the absence of competition for the contract reduces the size of the reward for a flawless design and, as a result, the temptation to renege on the relational contract is always strictly lower under augmented negotiations.<sup>21</sup> Thus, while auctions better cope with the screening problem, negotiations may turn out to be more effective in stimulating the supplier's investment.

The buyer's expected utility under augmented negotiations which induce  $e = 1$  in every period is:<sup>22</sup>

$$u^{AN} = v - (1 - \beta)(1 - \rho)k - E(c) - R(1) + f \quad (7)$$

By contrast a supplier expects to get  $R(1) - g - f$  in every period in which he is selected and invests. The buyer's problem is to choose rewards and the participation fee so as to maximize (7), subject to participation, incentive, and dynamic enforcement constraints. The next proposition shows under what condition augmented negotiations that attain  $e = 1$  in every period can be implemented.<sup>23</sup>

---

<sup>21</sup>When a supplier invests in an auction there is uncertainty as to whether or not he will be selected to produce. Moreover, the payoff associated with remaining idle is positive, unless the reward for a correct design is so large that an idle supplier does not stand a chance of winning the auction when at least one rival supplier invests.

<sup>22</sup>We focus on cost-plus contracts as, in our setting, the buyer cannot benefit from using fixed-price contracts in a direct negotiation.

<sup>23</sup>As for augmented auctions, we consider trigger strategies in which the parties cooperate with each other as long as they have observed a cooperative history. Public history at any given time  $t$  in which a negotiation is used just does not contain information on the price bids since these are not submitted.



**Proposition 2.** *Augmented negotiations that obtain  $e = 1$  are self-enforcing if the following buyer's dynamic enforcement constraint holds:*

$$\frac{\delta}{1-\delta} \underbrace{[(1-\beta)\rho k - g - (c_1^1 - c_N^N)]}_{u^{AN} - u^{auc}} \geq \frac{g}{(1-\beta)\rho} \quad (BDE^{AN})$$

*Proof.* In the Appendix. □

Several remarks are worth making. As long as augmented negotiations which implement  $e = 1$  are strictly profitable for the buyer, i.e.  $u^{AN} > u^{auc}$ , there always exists a threshold level of the discount factor  $\delta$  above which they can be sustained. As we have shown before, such threshold may fail to exist for augmented auctions even when they are efficiency-enhancing. This is because the suppliers can be induced to invest only if the expected information rent is larger than the investment cost.

Moreover, even when the (BCC) holds and augmented auctions generate a higher surplus than augmented negotiations, the buyer may need to adopt the latter procurement mode since it entails a strictly lower temptation to renege as  $\frac{g}{(1-\beta)\rho} < \frac{B(n,g)}{(1-\beta)\rho}$ . This is so because under augmented negotiations a supplier does not face any uncertainty as to whether or not he will be chosen to produce the good and he must just be provided with a moral-hazard rent.

Finally, note that the participation fee allows the buyer to fully extract the supplier's surplus. Namely,  $f^{AN} = \frac{\beta g}{(1-\beta)\rho}$  and the buyer's expected utility in a negotiation can be rewritten as follows:

$$u^{AN} = v - (1-\beta)(1-\rho)k - c_1^1 - g \quad (8)$$

As a result, it does not matter if the buyer switches trading party in every period as the supplier does not attach any weight to the possibility of being granted additional contracts.<sup>24</sup>

The model shows how the optimal procurement mode critically depends on the horizon of the relationship: while unrestricted auctions are optimal in the one-shot game, restricted auctions or negotiations may be optimal when the players interact frequently.<sup>25</sup> Stiffer competition may not benefit the buyer: a higher number of potential suppliers  $N$  increases the attractiveness of spot auctions and, as a result, may render superior relational contracts non-sustainable.

Up to now we have maintained the assumption that the buyer always delegates the task of designing the good to the suppliers. However, the buyer may be able to provide the technical drawings of the good herself. Then, if the game is not repeated or an efficiency-enhancing relational contract cannot be sustained, the buyer might find it profitable to develop the design of the good in-house and only delegate its production to a supplier. In the manufacturing industry, this practice is often referred to as *drawings supplied*. In contrast, when relational contracts that induce the investment are sustainable, the buyer can provide the interested suppliers with a list

---

<sup>24</sup>By contrast, if the buyer were unable to fully extract the supplier's surplus, it might be profitable to condition both rewards and the probability of renewing the contract on current performance. The renewal option would allow the buyer to sustain the relational contract more easily. The possibility of deferring some of the moral-hazard rent to future periods would reduce the per-period reward following a good outcome.

<sup>25</sup>This result can be reminiscent of Baker et al. (2011) and Che and Yoo (2001) in which the optimal governance structure and incentives for teams, respectively, are affected by the weight contracting parties place on the future of the relationship.

of the required performances, and rely on them to deliver the final design of the good. This practice is often called *black-box* or *drawings approved*.<sup>26</sup>

Our model predicts that when the task of designing the goods is delegated to the suppliers, a buyer tends to adopt either restricted auctions or direct negotiations. This is both desirable, because it is not efficient to have many suppliers bear the investment cost, and necessary, because it encourages the investment by creating enough information rent or reduces the size of the reward for a successful design. In contrast, when a buyer supplies the technical drawings herself, we should expect her to procure goods through open bidding. As the suppliers' investment does not have to be motivated, there is no use in restricting competition.

### 4.3 Empirical Evidence and Discussion

This section has highlighted how the buyer's objectives of selecting the most efficient supplier and solving the hidden-action problem may be conflicting. The buyer faces a trade-off: Unrestricted auctions guarantee that the lowest cost supplier will produce the good, whereas limiting competition is desirable when the potential suppliers must be motivated to undertake a project-specific investment. When there is more uncertainty about the correct specification of the good, the supplier's investment is more critical. In the economics literature, this uncertainty is often interpreted as an indication of the *complexity* of a project (see, for instance, Bajari and Tadelis, 2001, and Chakravarty and MacLeod, 2009). Therefore, one testable implication is that we should observe a more extensive use of negotiations or restricted auctions whenever goods are more complex. This prediction seems to be supported by empirical evidence on the construction industry. Bajari et al. (2009) analyze private sector building contracts awarded in Northern California during the years 1995-2000 and find that more complex projects are more likely to be negotiated. They also estimate an ordered logit which shows an inverse relationship between the complexity of the project and the competitiveness of the award procedure.<sup>27</sup>

The results of the model can help provide some insight on the stark differences between the buyer-supplier relationships in the Japanese and American car manufacturing industry up to the end of the 1980s and the subsequent adoption of Japanese-like supply-chain practices by the U.S. car makers.<sup>28</sup>

In the U.S., the buyer-supplier relationships had historically been adversarial. There the assemblers' engineers normally designed most of the parts and components of a car themselves. Then, the assemblers provided the suppliers with detailed drawings of the parts they needed to procure and asked them to submit a price bid. In doing so, they received no significant insight from the suppliers on how to improve the goods specification. Competitive bidding was open to a large number of suppliers and selection occurred solely on a price basis. This is in line with the

---

<sup>26</sup>In construction procurement, under the Design-Bid-Build project-delivery system the buyer only delegates the building phase to the supplier while under Design-Build the supplier also provides the design of the building.

<sup>27</sup>As proxies for complexities the authors use the (log) value of the project (engineers' estimated cost), the (log) square feet of the project, and the number of divisions which indicate the number of subcategories of work required to complete the project.

<sup>28</sup>In the discussion that follows we draw on a number of sources, such as Asanuma (1989); McMillan (1990, 1994); Dyer (1996); Roberts (2004); Womack et al. (2007).

predictions of our model: when the buyer does not expect the suppliers to make the investment, she does not restrict competition, chooses the lowest cost supplier, and develops the design of the good by herself.

In sharp contrast, Japanese car manufacturers had built a good-faith long-term relationship with their suppliers. The suppliers were normally given just performance specifications and were told to develop a prototype before getting a production order.<sup>29</sup> Suppliers were usually selected by restricted competition and they faced a limited number of competitors. Moreover, price had a marginal role in the selection choice while more weight was attached to other aspects, such as performance record and past relationships. As discrimination tended to act in favor of the incumbent, this selection procedure closely resembles augmented negotiations.<sup>30</sup> Furthermore, suppliers were not dismissed when their performance did not meet the expectations (Womack et al., 2007, pg.157), consistently with the finding of Propositions 1 and 2 where we show that design failures are tolerated and a supplier is not blacklisted provided that he accepts a penalty.<sup>31</sup> Our model suggests that Japanese assemblers restricted competition or adopted negotiation procedures to successfully delegate the design of the goods to their suppliers. Expecting the buyers to honor their informal promises to reward successful performances, suppliers were willing to undertake the project-specific investments.

As many observers argue, each system of relationships was probably optimal in its environment (see McMillan, 1994 and Roberts, 2004): The strategy pursued by the U.S. car makers had allowed them to dominate the industry for decades. Arguably, the increasing technical complexity of vehicles made valuable the involvement of the suppliers in the design of car parts and components.<sup>32</sup> In our model this would translate into a lower level of  $\beta$  that, as Propositions 1 and 2 highlight, increases the appeal of delegating the design to the suppliers.

Relative to the Big Three, the Japanese car makers were better positioned to receive some insight from their suppliers: They were producing more distinct products and were replacing models at a faster pace.<sup>33</sup> This more frequent interaction would imply a higher value associated with continuing the long-term informal relationship.

One of the triggers for the adoption of similar good-faith relationships between buyers and suppliers in the U.S. was the fierce competition from the Japanese car makers in the 1980s. The different supply-chain practices can, at least to some extent, account for the competitive

---

<sup>29</sup>The figures reported in Clark (1989, Table 1) help grasp the difference between Japanese and U.S. assemblers. While U.S. assemblers were delegating detail-engineering (i.e., the process of producing the drawings of a part) only for 16% of the parts in their cars, Japanese assemblers were resorting to the suppliers' engineers to supply the drawings for 62% of their car parts.

<sup>30</sup>As reported by McMillan (1990), a 1987 survey of small Japanese manufacturers found a considerable stability in the buyer-supplier relationship: 68% never changed their parent companies and only 7% changed three or more times.

<sup>31</sup>While in the Japanese buyer-supplier system the business was temporarily and partially shifted to a competitor, in our model the penalty takes a monetary form which allows the parties to settle at the end of each period.

<sup>32</sup>This was at least in part due to the growing use of electronic components which began in the 1970s and continues to the present day.

<sup>33</sup>See Womack et al. (2007), in particular Figure 5.2 and Figure 5.6. On the differences between the product lines of Toyota and Ford, see also Roberts (2004) (pp 38-39).

advantage that Japanese car manufactures had over their US counterparts during those years, as reported in the comprehensive study by Womack et al. (2007).<sup>34</sup> The adoption of Japanese-style supplier relations was accompanied by technological developments that dramatically shortened the time needed to redesign products and led to a proliferation of car models, which implied a higher value of a good-faith relationship also in the U.S. automotive industry.<sup>35,36</sup>

A similar pattern is observed in sophisticated electronics (Burt, 1989). At the end of the 1970s the share of worldwide copier revenues accruing to Xerox was falling rapidly. Relative to its Japanese competitors, Xerox had high manufacturing costs and slow product development. At that time, Xerox engineers designed almost all the copier components whose manufacture was typically outsourced to suppliers which included over 5,000 firms. Among the steps taken to turn around the company there was the restriction of the supplier base to 400 firms and the delegation of the design task to the suppliers who were required to provide blueprints. This was followed by a considerable fall in new product development time and costs and a reduction of net production costs.

## 5 Extensions and Robustness Checks

In this Section we consider three extensions or robustness checks. First, we assume that the buyer is able to invest in the initial specification of the good and we study the relationship between this investment and the procurement mode. Second, we examine how the results of the analysis carried out so far change when courts are able to verify a design failure. Third, we assume that the buyer can infer the suppliers' investment from observing the technical drawings so as to understand the role of hidden-action in determining our results.

### 5.1 Buyer's Investment in the Design of the Good

In this extension we build on the earlier discussion on the buyer's ability to provide the design of the good herself. We assume that the buyer can decide the extent to which the design of

---

<sup>34</sup>Suppliers' performance was unambiguously superior in Japan as can be seen, for instance, by the lower number of parts defects per car: 0.24 instead of 0.33 (Womack et al., 2007, Figure 6.1).

<sup>35</sup>The broad-ranging technological developments (e.g. computer-aided design) are documented in Milgrom and Roberts (1990), while for the proliferation of car models sold and produced in North America as well as the increased variety in body styles and chassis configurations see, for instance, the figures reported in Van Biesebroeck (2007).

<sup>36</sup>Other explanations for the change in the supplier relations in the U.S. automotive industry are provided in Legros and Newman (2008) and Taylor and Wiggins (1997). Legros and Newman (2008) show how shocks that initially affect only few firms can have widespread repercussions on the design of organizations in an entire industry. Then, the fall in revenues that the U.S. assemblers experienced because of the stiffer Japanese competition might have caused a decrease in the degree of control that buyers had in their relationship with their suppliers over several aspects of product and process development. Taylor and Wiggins (1997) argue that the drop in the cost of setting up a production run favored the adoption of the Japanese-style mode of procurement in the U.S.. They maintain that a distinguishing trait of Japanese-style procurement is that firms buy small lots more frequently and threat to cut off those suppliers who turn out to have provided low quality goods rather than inspect up-front large deliveries and refuse to buy the lots if the quality is deemed unsatisfactory, like the American firms traditionally do.

the good is delegated to a supplier. In particular, we consider the case in which the buyer can make an investment at the beginning of each period which affects the probability  $\beta$  that the specification of the good will be ex-post free from defects. In doing this, we draw on Bajari and Tadelis (2001) who were the first to envision an initial buyer's investment into planning that affects the likelihood that the design of a good is ex-post correct. A similar approach has since then been adopted by other authors, such as Ganuza (2007), Chakravarty and MacLeod (2009), and Tirole (2009). In particular, Tirole (2009) develops this idea further and provides the alternative interpretation of an investment in the completeness of the contract to which we might also adhere.

Formally, the buyer chooses the value of  $\beta \in [0, 1]$  at a cost given by the function  $T(\beta)$  which is strictly increasing,  $T'(\beta) > 0$ , strictly convex,  $T''(\beta) > 0$ , and with  $T'(0) = 0$ , and  $T'(1) = \infty$  so that there is always a positive probability that the specification of the project initially worked out by the buyer turns out to be defective. The buyer's investment in the specification of the good is known to all the players of the game and is made before the procurement mode is announced.

The optimal buyer's specification of the good clearly depends on whether or not the supplier invests. The socially efficient level of specification is such that the marginal social benefit of a more accurate specification of the good, i.e. the avoidance of  $k$  when the buyer's specification is correct, equals its marginal cost. First we define  $\beta^*$  as the socially efficient specification of the good when the supplier incurs the investment cost:

$$\beta^* \equiv \arg \min_{\beta \in [0,1]} (1 - \beta)(1 - \rho)k + T(\beta)$$

Thus,  $T'(\beta^*) = (1 - \rho)k$ . Analogously, we define  $\hat{\beta}$  as the socially efficient specification of the good when the supplier does not make the investment:

$$\hat{\beta} \equiv \arg \min_{\beta \in [0,1]} (1 - \beta)k + T(\beta)$$

Thus,  $T'(\hat{\beta}) = k$ . The buyer's specification of the good is more complete when no supplier is expected to invest. This is what happens in the one-shot game, irrespective of the adopted procurement mode, since the buyer must compensate for the lack of the supplier's investment. Thus,  $T'(\beta^{auc}) = T'(\beta^{neg}) = T'(\hat{\beta}) = k$ .

To make the problem interesting, we continue to assume that the supplier's investment is desirable also when the buyer can affect the likelihood of a design failure. To this end, we need to adapt Assumption 1 to the new setting by imposing that the social loss due to a failure of the design is minimized when the supplier invests, given the buyer's optimal specification of the good.

**Assumption 2.** *The following condition holds:*

$$(1 - \hat{\beta})k + T(\hat{\beta}) > g + (1 - \beta^*)(1 - \rho)k + T(\beta^*).$$

In the repeated game, the buyer's investment becomes part of the relational contract as it affects the incentives provided to the suppliers to undertake the investment.

The following proposition describes the optimal choice of  $\beta$  in augmented auctions and augmented negotiations and shows how this crucially depends on whether or not the buyer's dynamic enforcement constraint binds.

**Proposition 3.** *The optimal buyer's investment in the specification of the good in augmented auctions and augmented negotiations are*

$$T'(\beta^A) = \max \left\{ (1 - \rho)k - \mathbb{1} \left\{ \frac{1 - \delta}{\delta} \frac{B(n, g)}{(1 - \beta^A)^2 \rho} \right\}, 0 \right\}$$

$$T'(\beta^{AN}) = \max \left\{ (1 - \rho)k - \mathbb{1} \left\{ \frac{(1 - \delta)}{\delta} \frac{g}{(1 - \beta^{AN})^2 \rho} \right\}, 0 \right\}$$

where the indicator function  $\mathbb{1}$  takes value 1 if the buyer's dynamic enforcement constraint binds and 0 otherwise.

*Proof.* In the Appendix. □

The above proposition shows that the buyer makes the socially optimal investment in the specification of the good as long as her dynamic enforcement constraint is slack. Conversely, when the BDE binds, the buyer's choice of  $\beta$  is distorted away from efficiency. To provide an intuition for this result, consider that a more complete specification of the good raises the cost of incentives because of the moral hazard problem: if the design turns out to be correct, the buyer does not know whether this is due to the adequacy of her specification of the project or the supplier's technical drawings. As long as the BDE is slack, the positive relationship between the reward and  $\beta$  does not affect the buyer's investment choice. In contrast, when the BDE binds, the buyer finds it profitable to reduce the cost of incentives by under-investing in the specification of the good. When the incentive problem is especially severe, the buyer may decide to provide a totally opaque specification of the project.

When the supplier's reward for delivering successful drawings is very high, the buyer must distort  $\beta$  away from efficiency to sustain  $e = 1$ . As we have shown previously, the credibility problem may be more severe under augmented auctions and therefore the buyer may decide to adopt augmented negotiations in order to mitigate the distortion of the investment in the specification of the goods.

A significant investment in the specification of the good can be best interpreted as the buyer providing the design of the good, detailing the materials and the methods to be used and only outsourcing its manufacture to the supplier. In contrast, a small buyer's investment can be seen as a mere specification of the desired performance requirements that the good should fill.<sup>37</sup> In the stage game the buyer expects to receive no insight from the suppliers on how to better design the good. For this reason, she will have to make a very significant investment in its specification. In the presence of frequent interaction, the buyer can provide the potential suppliers with a more general specification of the good and Proposition 3 shows that she may

---

<sup>37</sup>We could have modeled the buyer's investment in the specification of the good as binary, so as to make the correspondence between such investment and the choice of delegating the design to a supplier more evident. However, by doing so, we would have missed the different incentives the buyer faces when she decides how much to specify the goods depending on the tightness of the BDE.

find it profitable to strategically under-specify the design of the good as the incentive problem becomes more severe.<sup>38</sup>

Given that auctions are always used in the absence of repeated interaction while negotiations are more likely to be used when interaction is frequent, our model suggests a relationship between the buyer's choice of the procurement mode and her investment in the specification of the good. We should observe that goods procured through auctions are specified to a larger extent than goods procured through negotiations.

Taking into account the buyer's investment into planning, our model also provides a complementary explanation to the finding of Bajari et al. (2009) that more experienced procurers are more likely to select contractors through auctions. The authors maintain that more experienced buyers have lower administrative costs as they are more familiar with the bureaucratic procedures associated with auctions. Through the lens of our model, a buyer with more experience might incur a lower cost to draw up a more complete contract. The equilibrium level of  $\beta$  would subsequently be higher allowing the buyer to focus on the screening problem as a design failure is less likely to occur.

## 5.2 Court-verifiable Design Failure

In the framework that we have developed the buyer can achieve the desired supplier's investment only through the use of relational contracts. In this subsection we make the assumption that a design failure can be verified by a court. While we relegate to Appendix B both a formal analysis and a discussion of the related case law supporting our modeling assumptions, below we present the most important implications of the possibility of verifying the failure of the design.

In this variant of the benchmark model set out in the previous sections, a supplier may be prompted to invest to avoid being obligated by a court to pay the buyer the damages due to a defective design. We find that turning to a court to certify the failure of the design does not necessarily solve the investment problem for two main reasons. First, the buyer is not always able to make her suppliers accountable for the accuracy of the design. An impressive number of legal cases associated with defective good specifications suggest that a formal delegation of the design task to a supplier does not make the buyer immune from liability. Second, even if the supplier is found liable, the standard rule used to determine damages is *expectation damages* which compensates the buyer for the loss she suffered because of the supplier's negligence. This exogenous punishment may not be enough to stimulate the supplier's investment.

Introducing the possibility that a court can verify a design failure in our model is straightforward. We assume that, after observing a design failure, the buyer may sue the supplier at a cost. This covers both the legal expenses and the cost that the court must incur to learn the details of the contract as well as of the design. The buyer will bear this cost but she will be reimbursed by the supplier if the court rules against him.

---

<sup>38</sup>Also in Tirole (2009) it is shown that relational contracting is associated with more incomplete contracts. In that paper the result is due to the possibility that the supplier may refrain from holding up the buyer after a design failure, whereas in our setting the buyer under-invests as she knows that she can profitably delegate the design of the good to the supplier.

The role of the court is to certify that the design is defective and to determine liability.<sup>39</sup> As the legal cases discussed in Appendix B suggest, in assessing liability the court will take into consideration how much discretion the supplier was granted. When the design is not delegated, such as in a Design-Bid-Build, the supplier has no say in the design and therefore he will not normally be held liable for defects. When the design is delegated, such as in a Design-Build, the risk of design is imperfectly shifted to the supplier. In particular, the supplier is liable unless he can demonstrate that he was not given much latitude in deciding the course of action. The likelihood that the supplier will not be held liable for a design failure is higher the more detailed the initial specification furnished by the buyer. Consistently, we assume that the probability that the court rules in favor of the buyer is decreasing in  $\beta$ .<sup>40</sup> The main results of this section can be summarized as follows.

1. The buyer might be able to induce the supplier's desired investment under both auctions and negotiations even in the absence of repetition. This requires that (i) the buyer be willing to sue the selected supplier if the design fails and (ii) that the supplier be willing to invest to reduce the expected value of the punishment.
2. Relative to negotiations, auctions require an additional necessary condition to induce the investment, which is the bidding-competition constraint, and entail a more demanding supplier's incentive compatibility constraint.
3. Under both auctions and negotiations, the buyer may find it profitable to reduce the completeness of the contract to satisfy the necessary conditions mentioned in point 1. However, a reduction in  $\beta$  may not be enough to stimulate the investment.
4. If they can, the parties will settle outside the courtroom so as to spare the cost of a lawsuit. Of course, bargaining will occur in the shadow of the law. We find that the possibility of settling outside the courtroom adversely affects the supplier's willingness to invest as it reduces the expected punishment a supplier faces if he chooses  $e = 0$ .
5. When interaction is repeated the buyer may be willing to implement relational contracts. This is so even when  $e = 1$  can be achieved in the stage game since the buyer can mitigate the distortion in the specification of the good. Also note that if the buyer is willing to sue, then the lawsuit option alters the supplier's dynamic enforcement constraint.

This subsection has shed light on how the presence of courts can help implement the desired investment level. This is a theme already explored in the economics literature, although attention

---

<sup>39</sup>Thus, we do not assume that the parties can turn to a court to enforce a formal contract which sets payments contingent on  $\xi$ . In the United States, the Uniform Commercial Code establishes that the parties can liquidate in the contract the damages for breach by either party, but "*only at an amount which is reasonable in the light of the anticipated or actual harm caused by the breach*". Moreover "*a term fixing unreasonably large liquidated damages is void as a penalty*." (see U.C.C. 2-718). Therefore, the rule to determine damages is ultimately decided by the courts.

<sup>40</sup>Kvaløy and Olsen (2009) assume a positive relationship between how well the contract terms are specified and the probability of verification. In contrast, we posit that a design failure can be costly verified by a court but there is uncertainty as to how the judge will rule. A more specified contract, leaving less discretion to the supplier, may increase the likelihood that the court rules against the buyer.



has mostly focused on breaches of contracts that occur before production or trade.<sup>41</sup> However, it is important to stress that there is still an important role played by informal incentives. There are at least three reasons why the results of this section do not undermine the previous part of the analysis. First, in many occurrences courts are unable to determine liability.<sup>42</sup> Second, even when they can, we have highlighted how several conditions must be fulfilled to induce the investment. These conditions are very strict and the buyer can do little to satisfy them. In either case relational contracts are needed for the supplier to invest. Third, even when these conditions are satisfied, the buyer may be better off using informal incentives in the repeated game.<sup>43</sup>

### 5.3 Observable Investment

Our model presents elements typical of both the hold-up literature, i.e. a non-verifiable project-specific investment, and of the principal-agent literature, i.e. the investment is non-observable. To understand which dimension has driven our results, in this section we assume the moral-hazard problem away by positing that the buyer can perfectly infer a supplier's investment from observing his drawings, though we maintain its non-verifiability by a court. The ex-post noisy signal of investment, which is also solely observable, is no longer needed to set the informal payments.

In the stage-game the literature on research contests has shown that the suppliers' investment can be attained only under contests.<sup>44</sup> As there is no legally verifiable piece of information which can be used to induce the suppliers to invest, it is not possible to solve the hold-up problem in one-shot negotiations (see Che and Hausch, 1999). In contrast,  $e_i = 1$  for each  $i \in \mathcal{N}$  may constitute an equilibrium of the one-stage auction game provided that the bidding competition constraint holds at  $n$ . This is because the buyer has an incentive to select the supplier who offers her the largest surplus. Therefore a supplier who has invested is rewarded. Below we show that in the presence of repeated interaction both auctions and negotiations can stimulate the investment. Furthermore, we find that the temptation to renege is always lower under augmented negotiations which may then better address the hold-up problem.

In the repeated game, the buyer can promise to pay the selected supplier a reward,  $r$ , contingent on  $e$ . Then the absence of competition does not prevent negotiations from encouraging investment, which is a significant difference from the literature on research contests. Relative to the non-observability case, the condition to sustain the relational contract is also milder:

$$\frac{\delta}{1-\delta}[(1-\beta)\rho k - g - (c_1^1 - c_N^N)] \geq g \quad (9)$$

---

<sup>41</sup>See for instance the work by Shavell (1984), Rogerson (1984), and Edlin and Reichelstein (1996) on how different damage measures used by courts affect relationship-specific investment decisions and that by Chung (1991) and Aghion et al. (1994) on efficient contracting. More recently, Chakravarty and MacLeod (2009) also discuss the effect of legal remedies when the contract can no longer be enforced, as in our case.

<sup>42</sup>The parties themselves may not have a proper understanding of what has caused the design to fail, as the Boeing lithium-ion batteries case illustrates.

<sup>43</sup>However, note that imperfect formal contracting may undermine superior relational contracts by increasing the buyer's fall-back position. This result is also found in other papers in the literature, such as Baker et al. (1994, 2011).

<sup>44</sup>See for instance Che and Gale (2003).

In augmented auctions, the bidding-competition constraint no longer prevents surplus-increasing relational contracts from being sustained. This represents the most remarkable difference with the hidden-action case and is due to the buyer's ability to reward a supplier who has invested even if he has not won the auction.

Below we expand the space of contracts to allow the buyer to exchange transfers  $r_i$  with each supplier after the investment decisions are made. By doing so, the buyer adopts an *employment contract*. Expressions (3) and (4) on the suppliers' and the buyer's utility functions change as follows:

$$\pi_{i,t} = (1 - \delta)E \sum_{\tau=t}^{\infty} \delta^{\tau-t} \{ [P(b_{\tau}) - c_{i,\tau}] q_{i,\tau}(b_{\tau}) + r_{i,\tau} e_{i,\tau} - g e_{i,\tau} - f_{i,\tau} \} \mathbb{1}_{i,\tau} \quad (10)$$

For all  $i \in \{1, \dots, N\}$  and

$$u_t = (1 - \delta)E \sum_{i=1}^N \sum_{\tau=t}^{\infty} \delta^{\tau-t} \{ [v - (1 - \beta)(1 - \rho e_{i,\tau})k - P(b_{\tau})] q_{i,\tau} - r_{i,\tau} e_{i,\tau} + f_{i,\tau} \} \mathbb{1}_{i,\tau} \quad (11)$$

As the following proposition shows, since augmented auctions entail a higher reneging temptation than augmented negotiations, the former may be harder to sustain than the latter even when they generate a higher surplus.

**Proposition 4.** *Augmented auctions that attain  $SW^A(n)$  are self-enforcing if the following buyer's dynamic enforcement constraint holds:*

$$\frac{\delta}{1 - \delta} [(1 - \beta)\rho k - ng - (c_n^n - c_N^N)] \geq ng \quad (12)$$

*Proof.* In Appendix B. □

If the buyer cannot adopt the employment contract, it is still possible to sustain  $e = 1$  by reimbursing those suppliers who have invested at time  $t$  through the participation fee paid at time  $t + 1$ . This clearly makes it harder to sustain the relational contract because the temporal lag further increases the buyer's temptation to renege.

## 6 Conclusions

In this paper we have examined the problem of a buyer who must induce her supplier(s) to undertake a project-specific non-observable investment prior to sign the contract. We have highlighted a trade-off between alternative procurement modes: while fixed-price auctions better address the screening problem, cost-plus negotiations are more effective in stimulating the supplier's investment.

Our model suggests that the buyer's choice of retaining/delegating the design task is related to the procurement mode. When the design of the good is delegated, we should observe restricted auctions or direct negotiations. In contrast, the in-house development of the design should be associated with unrestricted auctions. These findings are consistent with the procurement practices adopted in complex manufacturing industries. Moreover, our model predicts that goods

for which there is more uncertainty about the suitability of their design will be procured through negotiations. This result is borne out by the empirical literature on construction procurement.

We have shown that a reduction in the cost of investment increases the surplus generated by relational contracting and leads to a higher equilibrium number of solicited suppliers. Thus our model offers some important predictions about the evolution of the procurement practices in the manufacturing and construction industry, which have been experiencing radical transformations due to the widespread adoption of 3D printing. This has been dramatically reducing the costs and the developing time to make prototypes.<sup>45</sup>

In the paper we have not allowed for the possibility of collusion among suppliers in augmented auctions. In a related setting, Calzolari and Spagnolo (2009) show that the buyer can be better off if the suppliers are able to sustain a collusive agreement aimed at inflating the price paid to the awardee, since she can obtain higher quality goods. Likewise, in our set-up the buyer can benefit from collusion in prices among suppliers. This is because the suppliers may be more willing to make the precontractual investment as the awardee's expected payoff is larger than the information rent obtained in the absence of collusion. The buyer would not be concerned about the higher price paid to the winning bidder as she could extract the suppliers' expected rents through the participation fees.

We have assumed that the suppliers' precontractual investment increases the buyer's expected value of the project whereas it does not have any significant effect on the cost of production. Our approach can be seen as complementary to that of other authors who have studied precontractual investments whose effect is to shift downwards the suppliers' cost distribution with no impact on the expected value of the project to the buyer (see Tan, 1992, Laffont and Tirole, 1993, and more recently Loertscher and Riordan, 2014). In this latter case, repeated interaction is not necessary to stimulate investment.

Although the primary focus of our paper has been on private procurement, we may provide some insight on how the public sector should procure customized goods. Note that even if the parties' ability to exchange informal transfers faces external constraints, buyers can still come up with other forms of rewards to motivate the suppliers, such as additional contracts in different lines of business. Thus our model can be easily adapted to fit a public procurement setting. In the U.S., the Department of Defense often sponsors contests under the assumption that it can observe and select the best innovation. The Joint Strike Fighter program is one of its most celebrated contests and is also one of the most cited in the economics literature on research tournaments. In that contest, the Lockheed-Martin's X-35 prototype prevailed over the Boeing X-32's (McDonnell Douglas too intended to participate but its bid was rejected at an earlier stage). The trouble and the significant redesign which have since affected the development of the F-35 raise some questions on the ability of the sponsor to observe the best design at an early stage.<sup>46</sup> Then, repeated interaction, if available, can be a better driver of innovation than

---

<sup>45</sup>See, for instance, "A Third Industrial Revolution", The Economist, April 21, 2012, and "3D printing: Car-makers put brakes on prototype costs", The Financial Times, December 26, 2013, where it is also reported that "a Ford engineer would create a computer model of an intake manifold engine part and wait about four months for a prototype at a cost of \$500,000. With 3D printing, the car manufacturer can print the same part in four days at a cost of \$3,000."

<sup>46</sup>See, for instance, "Rough Ride for the F-35", The New York Times, July 27, 2014.

a research contest and, in this case, we have shown that negotiations may be favored.

## Appendix A

### Proof of Lemma 1

In the second-price reverse auction, each bidder submits a bid  $b_i$  and the lowest bid wins the contract. Suppose first that the contract is written in a fixed-price fashion, i.e.  $\gamma = 0$ . At the time of submitting his bid, the supplier's payoff is:

$$\pi_i = \begin{cases} \min_{j \neq i} b_j - c_i & \text{if } b_i < \min_{j \neq i} b_j \\ 0 & \text{if } b_i > \min_{j \neq i} b_j \end{cases}$$

If there is a tie, each lowest bidder has the same probability of winning the contract.

As the selected supplier will bear the cost of production, it is a weakly dominant strategy to reveal their costs of production. Thus,  $b_i = c_i$ . The lowest cost supplier wins the auction and his expected cost of production is  $c_n^n$ . The expected payment to the winning bidder amounts to the value of the second-smallest bid, that is  $EP(b) = c_{n-1}^n$ . Substituting these values in the buyer's expected utility function we attain:

$$u_{\gamma=0}^{auc} = v - (1 - \beta)k - c_{n-1}^n + \sum_{i \in \mathcal{N}} f_i \quad (A1)$$

The buyer charges  $f_i^{auc} = f_i^{auc} = \frac{1}{n}I(n)$  to induce the invited suppliers to accept to participate and fully extract their expected information rent. This yields

$$u_{\gamma=0}^{auc} = v - (1 - \beta)k - c_n^n \quad (A2)$$

which is monotonically increasing in  $n$ , hence  $n^{auc} = N$ .

Suppose now that the buyer auctions off cost-plus contracts, i.e.  $\gamma = 1$ . At the time of submitting his bid, the supplier's payoff is:

$$\pi_i = \begin{cases} \min_{j \neq i} b_j & \text{if } b_i < \min_{j \neq i} b_j \\ 0 & \text{if } b_i > \min_{j \neq i} b_j \end{cases}$$

If there is a tie, each lowest bidder has the same probability of winning the contract.

As the selected supplier will not bear the cost of production, the bids will not reflect their costs of production. Competition will lead to  $b_i = 0$  for all  $i \in \mathcal{N}$  and the supplier is selected randomly. As no supplier expects to collect a surplus in the bidding process,  $f_i = 0$ . The buyer's expected utility function is:

$$u_{\gamma=1}^{auc} = v - (1 - \beta)k - E(c)$$

which is smaller than (A2). Note that in the main text we write  $u_{\gamma=0}^{auc} = u^{auc}$ .

### Proof of Proposition 1

We split the proof in two parts. In Part 1 we show that (BCC) is a necessary condition to have an equilibrium in augmented auctions in which  $e_i = 1 \forall i \in \mathcal{N}$  and we characterize  $B(n, g)$ . In Part 2 we show that augmented auctions that achieve  $SW^A(n)$  are self-enforcing only if (BCC) and  $(BDE^A)$  hold.

## Part 1

Note first that if the contract is written in a cost-plus fashion, i.e.  $\gamma = 1$ , there cannot be a symmetric pure strategy equilibrium in an auction in which  $e_i = 1$  for all  $i \in \mathcal{N}$ . At the bidding stage, the suppliers would bid  $b_i = -R(e_i)$ , that is, they would be willing to pay up to the expected discretionary payment to be awarded the contract. If the rival suppliers invest, a supplier would expect to lose the investment cost  $g$  by investing. Hence, he would not invest. In the remainder of the proof we consider the case in which the contract is written in a fixed-price fashion, i.e.  $\gamma = 0$ .

Let us first show that if  $\frac{1}{n}I(n) < g$ ,  $e_i = 1 \forall i \in \mathcal{N}$  cannot be achieved. Suppose  $i$ 's  $n - 1$  rival suppliers are investing. If supplier  $i$  remains idle, his expected payoff is at least 0. If he invests, his expected payoff at the investment stage is:

$$E\pi_i(e_i = 1 | e_{-i} = 1) = \frac{1}{n}I(n) - g$$

Then  $\frac{1}{n}I(n) \geq g$  is a necessary condition for the suppliers to invest in a pure-strategy symmetric equilibrium. It does not guarantee investment, though. To this end, the buyer must set  $R(1) > R(0)$  so as to reduce the expected payoff of an idle supplier.

In what follows we assume that (BCC) is satisfied. Now we show that for a sufficiently large  $R(1) - R(0)$  the buyer can always induce all the suppliers to invest.

Recall that as the buyer holds second price auctions, it is a weakly dominant strategy for bidder  $i$  to bid  $b_i = c_i - R(e_i)$ . Suppose that  $i$  remains idle when at least one rival supplier  $j$  invests. Supplier  $i$  has no chance of winning the auction and his expected payoff is then 0 if  $\min b_i(e_i = 0) > \max b_j(e_j = 1)$ , that is if  $\underline{c} - R(0) > \bar{c} - R(1)$ , which can be rewritten as  $R(1) - R(0) > \bar{c} - \underline{c}$ . If this inequality holds and  $i$  invests, he wins if  $c_i < \min_{j \neq i} c_j$  for  $j \in \mathcal{N}$  such that  $e_j = 1$ . Suppose that there are  $m - 1 \leq n - 1$  investing bidders. Then,  $i$ 's expected payoff from investing when  $R(1) - R(0) > \bar{c} - \underline{c}$  is:

$$E\pi_i(e_i = 1 | m - 1 \text{ rivals invest}) = \frac{1}{m}I(m) - g$$

Therefore  $i$  is willing to invest when  $m - 1$  rivals invest if and only if  $\frac{1}{m}I(m) \geq g$ . Note that the left-hand side of this inequality reaches its minimum when all  $i$ 's  $n - 1$  rivals invest. In that case, the inequality becomes  $\frac{1}{n}I(n) \geq g$ , which is satisfied whenever (BCC) holds. In addition, note that if  $\underline{c} - R(0) = \bar{c} - R(1)$ , an idle supplier may win the auction when at least one of his rivals invests, but his expected payoff conditional on winning is 0. Therefore, if  $R(1) - R(0) \geq \bar{c} - \underline{c}$ , it is a weakly dominant strategy for each supplier  $i$  to invest when at least one rival invests.

However, setting  $R(1) - R(0) \geq \bar{c} - \underline{c}$  may not be enough when *all*  $i$ 's rivals remain idle. In that case  $i$ 's expected payoff from remaining idle is:

$$E\pi_i(e_i = 0 | e_{-i} = 0) = \frac{1}{n}I(n)$$

If  $i$  invests, his expected payoff is:

$$E\pi_i(e_i = 1 | e_{-i} = 0) = c_{n-1}^{n-1} - R(0) - (c_1^1 - R(1)) - g$$

where  $c_{n-1}^{n-1} - R(0)$  is the expected value of the smallest bid of  $i$ 's rivals and  $c_1^1$  is  $i$ 's expected cost of production. Then, for  $i$  to be willing to invest, it must also be that:

$$R(1) - R(0) \geq \frac{1}{n}I(n) + g + (c_1^1 - c_{n-1}^{n-1}) \quad (\text{A3})$$

Note that  $c_1^1 \geq c_{n-1}^{n-1}$  for any  $n \geq 2$ . Hence, if the buyer sets  $R(1) - R(0) \geq \max\{\bar{c} - \underline{c}, \frac{1}{n}I(n) + g + (c_1^1 - c_{n-1}^{n-1})\}$ , she ensures that a supplier  $i$  is willing to invest independently of what his rivals do.

To minimize her temptation to renege on the relational contracts, the buyer sets the minimum difference  $R(1) - R(0)$  which guarantees that  $e_i = 1$  for all  $i \in \mathcal{N}$  is the only equilibrium in the investment stage. We have denoted such minimum difference by  $B(n, g)$  and we have pointed out that  $B(n, g)$  is bounded above exactly by the maximum between  $\bar{c} - \underline{c}$  and  $\frac{1}{n}I(n) + g + (c_1^1 - c_{n-1}^{n-1})$ . This becomes the relevant value of  $B(n, g)$  when the  $(BCC)$  binds, that is when  $\frac{1}{n}I(n) = g$ . To see this, consider that in that case  $i$ 's expected payoff from investing when all the other suppliers are investing is:

$$E\pi_i(e_i = 1 | e_{-i} = 1) = \frac{1}{n}I(n) - g = 0$$

As a result,  $i$  is willing to invest also if what he expects to earn by remaining idle is 0, which requires  $R(1) - R(0) \geq \bar{c} - \underline{c}$ . Then to avoid that  $e_i = 0$  for all  $i \in \mathcal{N}$  is an equilibrium, the buyer must also make sure that  $R(1) - R(0) \geq \frac{1}{n}I(n) + g + (c_1^1 - c_{n-1}^{n-1})$ .

To show that  $B(n, g) > g$ , it is convenient to focus on the simplest case in which supplier  $i$  must be motivated to invest when all his  $n - 1$  rivals remain idle.<sup>47</sup> Notice that irrespective of whether  $e_i = 1$  or  $e_i = 0$ , with probability  $\frac{1}{n}$ ,  $i$  is the lowest-cost supplier and gets the information rent  $I(n)$ . As a result,  $i$ 's willingness to invest cannot depend on the expected information rent. Supplier  $i$  may be willing to invest to collect the prize  $B(n, g)$  when he is awarded the contract. When  $i$  invests, he wins the auction also when  $c_i > \min_{j \neq i} c_j$  and  $\min_{j \neq i} c_j < c_i < \min_{j \neq i} c_j + B(n, g)$ , in which case  $i$ 's payoff is  $B(n, g) - (c_i - \min_{j \neq i} c_j)$ , that is the actual prize he collects is reduced by the fact that his cost of production is not the lowest one. Hence,  $i$ 's surplus from investing when everyone else remains idle is:

$$B(n, g)Pr(c_i < \min_{j \neq i} c_j + B(n, g)) - (c_i - \min_{j \neq i} c_j)Pr(\min_{j \neq i} c_j < c_i < \min_{j \neq i} c_j + B(n, g)) - g$$

Supplier  $i$  weakly prefers to invest when all his rivals remain idle if

$$B(n, g)Pr(c_i < \min_{j \neq i} c_j + B(n, g)) \geq g + (c_i - \min_{j \neq i} c_j)Pr(\min_{j \neq i} c_j < c_i < \min_{j \neq i} c_j + B(n, g)) \quad (\text{A4})$$

On the left-hand side of the above inequality,  $B(n, g)$  is multiplied by a probability which takes value 1 when  $B(n, g) \geq \bar{c} - \underline{c}$  and is lower than 1 otherwise. On the right-hand side, the second addendum is always positive whenever  $B(n, g) > 0$ . Hence, we can conclude that  $B(n, g) > g$  whenever  $g > 0$ .<sup>48</sup>

<sup>47</sup>In a more general case a subset of  $i$ 's rivals invest. There,  $i$ 's expected payoff depends on whether his strongest rival has invested or not. The case on which we focus suffices to show that  $B(n, g) > g$  and it is more clear-cut.

<sup>48</sup>Formally, let  $\Phi_L$  be the distribution of the lowest order statistic of  $n - 1$  draws, i.e. the distribution of the strongest rival  $i$  faces. Taking into account  $i$ 's expectation over  $c_i$  and  $\min_{j \neq i} c_j$ ,  $i$  is willing to invest when all

We conclude Part 1 by pointing out that the relationship between  $B(n, g)$  and the number of solicited suppliers  $n$  is ambiguous. When fewer suppliers participate in the auction the probability that  $i$  wins increases. However, this is so irrespective of whether  $i$  himself invests or not. The magnitude of the positive change in the probability of winning depends, among other things, on the total number of bidders and the distribution  $\Phi$ . Therefore, holding the differential  $R(1) - R(0)$  constant, it might be that supplier  $i$  is not more motivated to invest when one less bidder participates in the auction.

## Part 2

Augmented auctions with  $n$  suppliers which obtain  $SW^A(n)$  in expectation with surplus division  $\hat{u}$  and  $\hat{\pi}_i$  for each  $i$  are self-enforcing if the following conditions hold:

1. The buyer's and the supplier  $i$ 's participation constraint for all  $i = 1, 2, \dots, N$ :

$$\hat{u} \geq u^{auc}; \quad \hat{\pi}_i \geq 0$$

2. The bidding-competition constraint

$$\frac{1}{n}I(n) \geq g \quad (\text{BCC})$$

3. The supplier's incentive compatibility constraint:

$$R(e_1) - R(e_0) \geq B(n, g)$$

4. The buyer's dynamic enforcement constraint which ensures that the buyer is always willing to honor her promised rewards:

$$-r_\xi + \frac{\delta}{1-\delta}\hat{u} \geq -\pi_d(\xi) + \frac{\delta}{1-\delta}u^{auc}$$

where  $\pi_d$  represents the deviation payoff a supplier attains by turning down the buyer's offer. The above constraint must hold for all  $\xi \in \{S, F\}$ .

5. Supplier  $i$ 's dynamic enforcement constraint which ensures that supplier  $i$  is always willing to accept the buyer's discretionary rewards:

$$r_\xi + \frac{\delta}{1-\delta}\hat{\pi} \geq \pi_d(\xi)$$

which must hold for all  $i$  and  $\xi \in \{S, F\}$ .

---

his rivals remain idle if:

$$\begin{aligned} & B(n, g) \left[ \int_{\underline{c}}^{\bar{c}} \left( 1 - \int_{\underline{c}}^c d\Phi_L(x - B(n, g)) \right) d\Phi_i(c) \right] \\ & \geq g + \int_{\underline{c}}^{\bar{c}} \left( \int_x^{x+B(n, g)} (c - x) d\Phi_i(c) \right) d\Phi_L(x) \end{aligned}$$



Augmented auction attaining  $SW^A(n)$  give the buyer an expected utility  $u^A(n)$ :

$$u^A(n) = v - (1 - \beta)(1 - \rho)k - EP^A(b) - R(1) + \sum_{i \in \mathcal{N}} f_i$$

where  $EP^A(b)$  is the expected value of the second-smallest bid in augmented auctions attaining  $SW^A(n)$  and is equal to  $c_{n-1}^n - R(1)$ . Then the buyer's expected utility in augmented auctions is

$$u^A = v - (1 - \beta)(1 - \rho)k - c_{n-1}^n + \sum_{i \in \mathcal{N}} f_i$$

while supplier  $i$ 's expected profit at the beginning of each period is:

$$\pi_i^A(n) = \frac{1}{n}I(n) - g - f_i$$

The buyer will optimally set  $f_i = \frac{1}{n}I(n) - g$  for all  $i \in \mathcal{N}$  so as to extract all the suppliers' expected surplus from participating in augmented auctions. Substituting this value into the buyer's expected utility, we attain:

$$u^A = v - (1 - \beta)(1 - \rho)k - c_n^n - ng$$

Note that the rewards promised to the suppliers do not affect directly the buyer's utility. However, promising an excessively high reward increases the buyer's temptation to renege. The incentive compatibility constraint guarantees that in every period  $t$  each supplier prefers  $e = 1$  to  $e = 0$ . The constraint can be rewritten as follows:

$$[\beta + (1 - \beta)\rho]r_S + (1 - \beta)(1 - \rho)r_F \geq \beta r_S + (1 - \beta)r_F + B(n, g)$$

The above condition boils down to

$$r_S^A \geq \frac{B(n, g)}{(1 - \beta)\rho} + r_F^A$$

To determine the relevant supplier's dynamic enforcement constraint, note that if supplier  $i$  rejects the buyer's reward, he gets 0 irrespective of  $\xi$ , i.e.  $\pi_d = 0$  for  $\xi \in \{S, F\}$ . Moreover,  $r_S$  needs to be strictly higher than  $r_F$  to encourage the investment. The relevant constraint is then:

$$\frac{\delta}{1 - \delta}\pi^A \geq -r_F^A$$

By the same token, the relevant buyer's dynamic enforcement constraint is associated with the occurrence of  $\xi = S$ , in which case the buyer should pay a higher reward:

$$\frac{\delta}{1 - \delta}[u^A(n) - u^{auc}] \geq r_S^A \quad (BDE^A)$$

Since  $r_S^A$  increases in  $r_F^A$ , to facilitate the implementation of the augmented auctions yielding  $SW^A$  it is efficient to set  $r_F^A$  and  $r_S^A$  in such a way that the supplier's incentive compatibility and dynamic enforcement constraints bind. Since a supplier does not expect to obtain any rent from participating in an auction, the buyer cannot impose any discretionary penalty on a supplier following a failure:

$$r_F^A = 0$$

Therefore, after a success the supplier gets:

$$r_S^A = \frac{B(n, g)}{(1 - \beta)\rho}$$

These rewards are set in such a way that the BDE can be more easily satisfied. By promising a higher reward, the utility of the buyer would not be altered but it would be harder to satisfy the BDE constraint. Knowing the optimal promised rewards  $r_\xi^A$  and observing  $\xi$  and  $r_\xi$ , the suppliers who are not selected in a given period to produce are able to detect a deviation and determine the identity of the player who has cheated.

## Proof of Proposition 2

The buyer will be willing to implement augmented negotiation if they enable her to improve upon *spot* auctions, that is, if  $u^{AN} \geq u^{auc}$ . The buyer chooses the rewards to maximize (7) subject to the suppliers' participation, incentive and dynamic enforcement constraints, her participation and dynamic enforcement constraints.

The supplier's incentive compatibility constraint ensures that each selected supplier is willing to make the unobservable investment. To determine this and the other constraints, note that the participation fee allows the buyer to extract the entire supplier's moral-hazard rent. Then a supplier does not attach any value to the future relationship with the buyer. The incentive compatibility constraint takes the following form:

$$[\beta + (1 - \beta)\rho]r_S + (1 - \beta)(1 - \rho)r_F - g \geq \beta r_S + (1 - \beta)r_F$$

Unlike an auction, the expected discretionary payment  $R(e_i)$  is not incorporated in any bid. It is straightforward to retrieve the optimal payments:

$$r_F^{AN} = 0; \quad r_S^{AN} = \frac{g}{(1 - \beta)\rho}.$$

The fee  $f^{AN}$  is optimally set equal to  $\frac{\beta g}{(1 - \beta)\rho}$  to ensure the supplier's participation. Buyer's utility in augmented negotiations can be written as follows:

$$u^{AN} = v - (1 - \beta)(1 - \rho)k - c_1^1 - g \quad (A5)$$

where  $c_1^1 = E(c) = \int_{\underline{c}}^{\bar{c}} x d\Phi(x)$ . The supplier's dynamic enforcement constraint is trivially satisfied while the buyer's dynamic enforcement constraint takes the following form:

$$\frac{\delta}{1 - \delta} \underbrace{[(1 - \beta)\rho k - g - (c_1^1 - c_N^N)]}_{u^{AN} - u^{auc}} \geq r_S^{AN} = \frac{g}{(1 - \beta)\rho} \quad (BDE^{AN})$$

Off-the-equilibrium path, it must be that the buyer is willing to exclude a supplier who has reneged on the relational contract. The threat of excluding the supplier is credible as it does not affect the buyer's utility: the expected cost of production will continue to be  $c_1^1$ .

### Proof of Proposition 3

In augmented auctions the expected buyer's utility when  $SW^A(n)$  is attained and  $\beta$  is affected by her investment is given by the following modified version of equation (6):

$$u^A(n, \beta) = v - (1 - \beta)(1 - \rho)k - c_n^n - ng - T(\beta) \quad (6')$$

To attain this expected utility, a modified version of the buyer's dynamic enforcement constraint must hold. This allows for potential differences in both the buyer's investment cost,  $T(\beta)$ , and in the optimal level of specification of the good,  $\beta$ , between the repeated and the stage game:

$$\frac{\delta}{1 - \delta} \underbrace{[(1 - \beta)\rho k + (\beta - \hat{\beta})k + T(\hat{\beta}) - T(\beta) - ng - (c_n^n - c_N^N)]}_{u^A(n) - u^{auc}} \geq r_S^A \quad (A6)$$

where

$$r_S^A = \frac{B(n, g)}{(1 - \beta)\rho}$$

Moreover, also the bidding-competition constraint  $\frac{1}{n}I(n) \geq g$ , which is unaffected by the choice of  $\beta$ , must hold. At stage 1 the buyer chooses a non-negative value of  $\beta$  to maximize this program.

Let  $\lambda$  be the Karush-Kuhn-Tucker multiplier of (A6). The Lagrangian can be written as follows:

$$\begin{aligned} L(\beta; \lambda) = & v - (1 - \beta)(1 - \rho)k - c_n^n - ng - T(\beta) \\ & + \lambda \left\{ \frac{\delta}{1 - \delta} [(1 - \beta)\rho k + (\beta - \hat{\beta})k + T(\hat{\beta}) - T(\beta) - ng - (c_n^n - c_N^N)] \right. \\ & \left. - \frac{B(n, g)}{(1 - \beta)\rho} \right\} \end{aligned} \quad (A7)$$

As a first case, suppose that at the optimum  $\lambda^A = 0$ , that is the buyer's dynamic enforcement constraint is slack. Then the derivative of the Lagrangian with respect to  $\beta$  yields:

$$\frac{\partial L}{\partial \beta}(\beta^A; \lambda^A) = (1 - \rho)k - T'(\beta^A) \leq 0$$

As  $\beta^A$  takes a positive value, the optimal investment in augmented auctions when the BDE constraint is slack is:

$$T'(\beta^A) = (1 - \rho)k \quad (A8)$$

which is socially efficient, since the suppliers make the investment  $e = 1$ .

Then, consider what happens when the BDE constraint binds. The value of  $\beta^A$  can be retrieved from the BDE:

$$\begin{aligned} T(\beta^A) = & (1 - \beta^A)\rho k + (\beta^A - \hat{\beta})k + T(\hat{\beta}) - (c_n^n - c_N^N) - ng \\ & - \frac{1 - \delta}{\delta} \left[ \frac{B(n, g)}{(1 - \beta^A)\rho} \right] \end{aligned} \quad (A9)$$

Taking the derivative with respect to  $\beta$  we obtain:

$$T'(\beta^A) = (1 - \rho)k - \frac{1 - \delta}{\delta} \frac{B(n, g)}{(1 - \beta^A)^2 \rho} \quad (A10)$$

which takes a positive value for  $\delta$  sufficiently high.

To conclude, putting together (A8) and (A10) we obtain that in augmented auctions the buyer's investment is given by the following expression:

$$T'(\beta^A) = \max \left\{ (1 - \rho)k - \mathbb{1} \left\{ \frac{1 - \delta}{\delta} \frac{B(n, g)}{(1 - \beta^A)^2 \rho} \right\}, 0 \right\} \quad (\text{A11})$$

where the indicator function  $\mathbb{1}$  takes value 1 if the BDE binds and 0 otherwise.

Note that the objective function is concave and the constraint is convex so that the necessary conditions are also sufficient for optimality.

In augmented negotiations, the buyer's expected utility is

$$u^{AN} = v - (1 - \beta)(1 - \rho)k - c_1^1 - g - T(\beta) \quad (\text{A12})$$

subject to the buyer's dynamic enforcement constraint:

$$\frac{\delta}{1 - \delta} \underbrace{[(1 - \beta)\rho k - g + (\beta - \hat{\beta})k + T(\hat{\beta}) - T(\beta) - (c_1^1 - c_N^N)]}_{u^{AN} - u^{auc}} \geq r_S^{AN} \quad (\text{A13})$$

where

$$r_S^{AN} = \frac{g}{(1 - \beta)\rho}$$

The buyer chooses a non-negative value of  $\beta$  to maximize this program. Let  $\lambda$  be the Karush-Kuhn-Tucker multiplier of (A13). The Lagrangian can be written as follows:

$$\begin{aligned} L(\beta; \lambda) = & v - (1 - \beta)(1 - \rho)k - c_1^1 - g - T(\beta) \\ & + \lambda \left\{ \frac{\delta}{1 - \delta} [(1 - \beta)\rho k - g + (\beta - \hat{\beta})k + T(\hat{\beta}) - T(\beta) \right. \\ & \left. - (c_1^1 - c_N^N)] - \frac{g}{(1 - \beta)\rho} \right\} \end{aligned} \quad (\text{A14})$$

First, suppose that at the optimum  $\lambda^{AN} = 0$ , that is the buyer's dynamic enforcement constraint is slack. Then the derivative of the Lagrangian with respect to  $\beta$  yields:

$$\frac{\partial L}{\partial \beta}(\beta^{AN}; \lambda^{AN}) = (1 - \rho)k - T'(\beta^{AN}) \leq 0$$

As  $\beta^{AN}$  takes a nonnegative value, the optimal investment in augmented auctions when the BDE constraint is slack is:

$$T'(\beta^{AN}) = (1 - \rho)k \quad (\text{A15})$$

which is socially efficient.

Then, consider the case in which the BDE constraint binds. The value of  $\beta^{AN}$  can be retrieved from the BDE:

$$T(\beta^{AN}) = (1 - \beta^{AN})\rho k - g + (\beta^{AN} - \hat{\beta})k + T(\hat{\beta}) - (c_1^1 - c_N^N) - \frac{1 - \delta}{\delta} \frac{g}{(1 - \beta^{AN})\rho} \quad (\text{A16})$$

Taking the derivative with respect to  $\beta$  we obtain:

$$T'(\beta^{AN}) = (1 - \rho)k - \frac{(1 - \delta)}{\delta} \frac{g}{(1 - \beta^{AN})^2 \rho}. \quad (\text{A17})$$

Again, when the right-hand side of the above expression is negative,  $\beta^{AN} = 0$ .

Note that the objective function is concave and the constraint is convex so that the necessary conditions are also sufficient for optimality.

## Appendix B

### Court-verifiable Design Failure

#### Related Case Law

An examination of the existing case law sheds light on why the buyer is not always able to make her suppliers accountable for the accuracy of the design. There is an impressive number of legal cases associated with defective good specifications which suggest that a formal delegation of the design task to a supplier does not make the buyer immune from liability.<sup>49</sup> One of the most important construction law cases in the United States is *United States v. Spearin*<sup>50</sup> which established that a supplier who followed the plans and specifications provided by a buyer could not be held responsible for consequences of defects. This is what is now commonly known as the *doctrine of implied warranties*. As subsequent cases have clarified, the warranty applies only to “design specifications” in which the buyer provides the supplier with a detailed road map from which he cannot deviate, while the warranty does not attach in the case of “performance specifications” wherein the buyer only describes the objective to be achieved.<sup>51</sup> In practice, the distinction between design and performance specifications is not always clear and contracts contain both method requirements and performance elements.<sup>52</sup> One approach that courts frequently follow to determine liability for a defective design is to evaluate how much discretion the contract gives the supplier to perform the work<sup>53</sup>. The same argument applies to the various project-delivery systems, included the Design-Build where, as opposed to Design-Bid-Build, the builder also provides the design of the project. Although Design-Build is often considered as a way to shift liability for defects from the buyer to the supplier, if the supplier reasonably relies upon the specification provided by the buyer, he will not be held accountable for flaws in

---

<sup>49</sup>A tremendously helpful source of information is provided by Transportation-Research-Board (2013). Many cases arise out of construction projects, although some can be found also in other industries (e.g. product sales, research and development). Note that while we continue to use the terms buyer and supplier, in the building sector they are commonly referred to as the owner and the contractor, respectively.

<sup>50</sup>248 U.S. 132, 39 S. Ct. 59, 63 L. Ed. 166 (1918).

<sup>51</sup>This general distinction between the two types of specifications is made in the seminal *J.L. Simmons Co. v. United States*, 188 Ct. Cl. 684, 412 F.2d 1360, 1362 (1969). Other cases have made clear that “design specifications” create an obligation for the supplier. *PCL Construction Services, Inc. v. United States* - 47 Fed. Cl. 745 (2000) states:

The warranty applies only to “design specifications” because only by utilizing specifications in that category does the government deny the contractor’s discretion and require that work be done in a certain way.

<sup>52</sup>As noted by the court in the case *Utility Contractors Inc. v. United States* - 8 Cl. Ct. 42 (1985):

The court has difficulty in believing that every government contract entered into can so neatly be placed in such black and white terms as design specification or performance contract. The court does not necessarily find that these terms have to be so mutually exclusive. Certainly one can find numerous government contracts exhibiting both performance and design specifications characteristics.

<sup>53</sup>See for instance *Martin Construction Inc. v. United States* - 102 Fed. Cl. 562 (2011) and the already cited *PCL Construction Services* case.

the design. The seminal case in this area is *M.A. Mortenson Co.*<sup>54</sup> where the final design was similar to that shown in the solicitation documents and was approved by the buyer. The Armed Services Board of Contract Appeals (ASBCA) held that the buyer had impliedly warranted the technical information provided in the drawings and the supplier had reasonably relied on their adequacy.

## Economic Environment

The timing of the benchmark model is enriched in two ways. At the beginning of each period, the buyer formally announces whether she retains or delegates the design of the good to the supplier. At the end of each period, after uncertainty has resolved, the buyer can sue the supplier at a cost  $l$ . As discussed in the paper,  $l$  covers both the cost of the lawsuit and the cost of the effort and time needed to go through the details of the contract and the project. The court assesses whether there has been a failure and if the design is found defective it determines liability. For simplicity, let us assume that the court perfectly learns a failure if  $l$  is incurred. Note that the parties cannot turn to the court to enforce contracts which set rewards and punishments contingent on  $\xi$ . The court can only obligate the supplier to pay the expectation damages to the buyer if it assesses that the design was flawed and holds that this was due to the supplier's negligence. As the court might be unable to measure the entire loss suffered by the buyer who has received a flawed product, let us assume that the supplier may be asked to reimburse  $\tilde{k} \in (0, k]$ .<sup>55</sup>

As explained above, the existing legal cases suggest that the more detailed the initial specification provided by the buyer, the lower the likelihood that the supplier will be held liable for a design failure. To capture this, let us assume that the probability that the supplier is found liable is  $\varphi(\beta)$ , which is strictly decreasing in  $\beta$  with  $\varphi(0) = 1$  and  $\varphi(1) = 0$ . One comfortable option could be that  $\varphi(\beta) = 1 - \beta$ . Moreover, if the buyer publicly announces that the design is not delegated, the court will never rule against the supplier in case of a design failure.

## One-stage Negotiation

Consider now how the stage game changes when we introduce the possibility of costly verifying a design failure. We start by considering a negotiation setting. When the buyer formally delegates the design of the good to the supplier, she is willing to sue the contractor after a failure only if the following condition holds:<sup>56</sup>

$$\tilde{k} + l \geq \frac{l}{\varphi(\beta^{neg})} \quad (\text{A18})$$

To see why, consider that after uncertainty is resolved the buyer is willing to sue only if the expected benefits, i.e. the recovery of a fraction of the damages due to a failure, more than offset the cost, i.e. the legal expenses which will not be reimbursed if the buyer is found liable:

$$\varphi(\beta^{neg})\tilde{k} \geq (1 - \varphi(\beta^{neg}))l$$

---

<sup>54</sup>ASBCA No. 39978, 93-3 BCA 26,189 (1993).

<sup>55</sup>It may be difficult for the court to assess the reputation damages and the loss of customers that the buyer experiences, especially if the buyer is not the final user of the good and has marketed a defective product.

<sup>56</sup>We are implicitly assuming that the buyer cannot commit to sue the supplier after a design failure.

rearranging and summing  $l$  to both sides, we can retrieve (A18).

If (A18) does not hold, the supplier knows that the buyer will not sue him if a failure occurs. Then, he has no incentives whatsoever to make the investment. As a consequence, (A18) is a necessary condition for the supplier to invest. However, it is not sufficient because the supplier may still be unwilling to bear the investment cost. Therefore, a second condition that must be satisfied for the supplier to invest is the following:

$$\tilde{k} + l \geq \frac{g}{(1 - \beta^{neg})\rho\varphi(\beta^{neg})} \quad (\text{A19})$$

To see this, consider the supplier's incentives to invest:

$$-(1 - \beta^{neg})(1 - \rho)\varphi(\beta^{neg})(\tilde{k} + l) - g \geq -(1 - \beta^{neg})\varphi(\beta^{neg})(\tilde{k} + l)$$

When the supplier can be sued, just covering the cost of production is not enough to induce his participation. The buyer chooses the participation fee and  $\beta^{neg}$  to maximize her utility given (A18) and (A19). Let us determine the solution for the case in which the supplier's investment can be induced. The fee is set in such a way that the supplier is willing to participate:

$$f^{neg}(\beta^{neg}) = g + (1 - \beta^{neg})(1 - \rho)\varphi(\beta^{neg})(\tilde{k} + l)$$

Substituting  $f^{neg}(\beta^{neg})$  into the buyer's expected utility function, it is possible to note that the probability of winning the lawsuit does not directly affect the buyer's utility:

$$u^{neg} = v - (1 - \beta)(1 - \rho)(k + l) - g - c_1^1 - T(\beta) \quad (\text{A20})$$

The owner will maximize (A20) subject to (A18) and (A19). If at  $\beta^{neg}$  the two constraints are slack, then  $\beta^{neg}$  satisfies:

$$T'(\beta^{neg}) = (1 - \rho)(k + l) \quad (\text{A21})$$

which is larger than the first-best specification level, as defined in Assumption 2, because of the legal costs  $l$ .

The picture changes dramatically if at the value of  $\beta$  that satisfies (A21), either (A18) or (A19) is not satisfied. Note that (A18) is the relevant constraint if  $l \geq \frac{g}{(1 - \beta^{neg})\rho}$ . In that case, we set  $\tilde{k} + l = \frac{l}{\varphi(\beta)}$  and the buyer chooses  $\beta$  to maximize

$$u^{neg} = v - (1 - \beta)(1 - \rho)(k - \tilde{k} + \frac{l}{\varphi(\beta)}) - g - c_1^1 - T(\beta)$$

Then the optimal specification of the project should satisfy:

$$T'(\beta^{neg}) = (1 - \rho) \left[ (k - \tilde{k}) + l \frac{\varphi(\beta^{neg}) + (1 - \beta^{neg})\varphi'(\beta^{neg})}{(\varphi(\beta^{neg}))^2} \right]$$

Note that such optimal value of  $\beta$  may not exist as  $\varphi'(\cdot) < 0$ . Analogously, if  $l < \frac{g}{(1 - \beta^{neg})\rho}$ ,  $\tilde{k} + l$  should be set equal to  $\frac{g}{(1 - \beta^{neg})\rho\varphi(\beta)}$ . Once this value is plugged into (A20), the first-order condition requires that the following hold:

$$T'(\beta^{neg}) = \frac{(1 - \rho)g\varphi'(\beta^{neg})}{\rho(\varphi(\beta^{neg}))^2} + (1 - \rho)(k - \tilde{k})$$

Note that the first element of the right-hand side is negative while the second is positive and decreasing in the difference between  $k$  and  $\tilde{k}$ .<sup>57</sup>

In conclusion, there are evident limits to the possibility of changing the specification of the good to induce the supplier's investment. In general, it is more difficult to stimulate the supplier's investment the lower the damages that the court is able to assess,  $\tilde{k}$ . Higher legal costs  $l$  make it more difficult to satisfy (A18), i.e. they adversely affect the willingness of the buyer to sue. However, provided that (A18) is met, higher legal costs increase the expected punishment that the supplier faces if he does not invest and therefore they ease the fulfillment of condition (A19). Also note that even when the two constraints are slack, the buyer's investment in the specification of the good is socially inefficient and this departure from efficiency may undermine the benefits of the supplier's investment. For these reasons, the buyer may end up choosing not to delegate the design of the good.

### Settlement Outside the Courtroom

Irrespective of how the bargaining power is distributed ex-post, when uncertainty resolves, the parties might be able to settle outside the courtroom so as to spare the legal costs  $l$ . In the real world lawsuits occur, arguably because the parties have different beliefs about whom is liable for the observed failure or because one of the parties may be unable to settle outside the courtroom.<sup>58</sup> Although the parties do not go to trial, the settlement will occur in the shadow of the law, that is, in the bargaining the parties will take into account what a judge would rule. The first observation is that the settlement will occur only if the contractor anticipates that the buyer is willing to sue, i.e. if  $\tilde{k} + l \geq \frac{l}{\varphi(\beta^{Ren})}$ . If they go to trial the buyer expects to receive  $\varphi(\beta^{Ren})(\tilde{k} + l)$  at cost  $l$ .<sup>59</sup> Then what the parties save by avoiding trial is the cost  $l$ . Let  $\alpha \in [0, 1]$  be the buyer's share of the gains from settling outside the courtroom. The supplier pays the buyer  $Ren = \varphi(\beta^{Ren})(\tilde{k} + l) - \alpha l$ . In general note that the punishment that the supplier expects to incur if he remains idle is reduced if the parties can settle outside the courtroom and decreases in his bargaining power. Clearly, this has negative implications for his willingness to invest. Condition (A19) becomes:

$$(1 - \beta^{Ren})\rho Ren(\beta^{Ren}) \geq g$$

The participation fee is

$$f^{Ren}(\beta^{Ren}) = g + (1 - \beta^{Ren})(1 - \rho)Ren(\beta^{Ren})$$

If at  $\beta$  that satisfies the following

$$T'(\beta^{Ren}) = (1 - \rho)k$$

---

<sup>57</sup>As for the second-order conditions, note that if  $\varphi(\beta) = 1 - \beta$ , the constraints are always convex functions.

<sup>58</sup>The fact that most of the legal cases examined involve the government seems to support this latter hypothesis. Governmental officials may not have the discretion to solve the disputes outside the courtroom and should be forced to sue the suppliers to recover the alleged damages.

<sup>59</sup>Throughout we have assumed that the parties do not update the belief about whom is going to be ruled against in the court after observing the design failure. However, this is inconsequential and can be relaxed with no impact on the results.



the constraints are satisfied, then the buyer's investment in the specification of the good along with the supplier's investment attain first-best. If either constraint is not satisfied at that  $\beta$ , then a reasoning akin to that set forth in the previous subsection applies.

### One-shot Auction

As in the case of a negotiation with a single supplier, a necessary condition for the bidders to invest is that the buyer will sue the selected supplier after observing a design failure, that is  $\tilde{k} + l \geq \frac{l}{\varphi(\beta^{auc})}$ . Provided that this condition is satisfied, the suppliers will be willing to invest only if this may help them win the auction. This requires that the bidding-competition constraint is satisfied:

$$\frac{1}{n}I(n) \geq g \quad (\text{A22})$$

In addition it must be that

$$(1 - \beta^{auc})\rho\varphi(\beta^{auc})(\tilde{k} + l) \geq B(n, g) \quad (\text{A23})$$

The expected value of the second-smallest bid is given by:

$$EP(b|\beta^{auc}) = c_{n-1}^n + (1 - \beta^{auc})(1 - \rho)\varphi(\beta^{auc})(\tilde{k} + l)$$

The buyer will choose  $\beta$  to maximize her expected utility:

$$\begin{aligned} u^{auc}(n) &= v - EP(b) - (1 - \beta)(1 - \rho)(k + l) + (1 - \beta)(1 - \rho)\varphi(\beta)(\tilde{k} + l) - nf - T(\beta) \\ &= v - (1 - \beta)(1 - \rho)(k + l) - ng - c_n^n - T(\beta) \end{aligned}$$

subject to the constraints above described. When no constraint binds at the optimum, the level of the investment is equal to that seen in a one-shot negotiation. Moreover, similar conditions to those seen for the negotiation case can be obtained when either constraint is not satisfied. When we allow for a settlement in the shadow of the law, the main point made here does not change.

### Repeated Interaction and Implicit Incentives

The main question we want to address here is whether there is still a role for the use of relational contracts when courts can certify design failures. Three cases must be considered.

1. First note that the buyer may be unable to satisfy the constraints needed to induce the supplier's investment in the stage game. In particular, the buyer may be unwilling to sue the supplier after  $\xi = F$ . In this case, the results of the benchmark model are unaffected by the presence of courts.
2. Suppose that the buyer may be willing to sue, but she is still unable to provide enough incentives for the suppliers to undertake the investment. The buyer will make use of relational contracts to stimulate the investment but the presence of courts affects the relevant Supplier's Dynamic Enforcement Constraint, *SDE*: if the supplier refuses to

accept the (negative) discretionary payment  $r_F$ , the buyer will sue him. In particular  $SDE$  in renewable procurement contracts becomes:

$$r_F \geq -\varphi(\beta)(\tilde{k} + l) + \alpha l$$

A corresponding analysis can be carried out for augmented auctions and yields similar insights.

3. Suppose that  $e = 1$  can be achieved in the static game, but requires to distort  $\beta$  away from its efficient level. Then the buyer may make use of relational contracts to mitigate such distortion. However, by raising the buyer's fall-back position, the presence of courts can hinder superior relational contracting.<sup>60</sup>

## Observable Investment - Proof of Proposition 4

With the employment contract the buyer can promise a transfer  $r_i$  to each supplier contingent on  $e$ . Consider the following reward schedule: a supplier receives  $r(e_1) = g$ , if he has invested,  $r(e_0) = 0$  if he has remained idle. This induces the suppliers to invest. The buyer will then set  $f = \frac{1}{n}I(n)$  to extract the expected information rent from each supplier. The buyer's dynamic enforcement constraint is:<sup>61</sup>

$$\frac{\delta}{1-\delta}[(1-\beta)\rho k - ng - (c_n^n - c_N^N)] \geq ng$$

If the buyer cannot exchange transfers with each suppliers after the investment is observed, she can reimburse the suppliers with a one-period delay through the participation fee. Therefore  $f_{i,t} = \frac{1}{n}I(n) - \frac{g}{\delta}$  if  $i$  invested at time  $t-1$  and  $f_{i,t} = \frac{1}{n}I(n)$  otherwise. The condition to ensure  $e = 1$  becomes:

$$\frac{\delta}{1-\delta}[(1-\beta)\rho k - ng - (c_n^n - c_N^N)] \geq \frac{ng}{\delta}$$

## References

- Aghion, P., Dewatripont, M., and Rey, P. (1994). Renegotiation design with unverifiable information. *Econometrica: Journal of the Econometric Society*, pages 257–282.
- Andrews, I. and Barron, D. (2013). The allocation of future business: Dynamic relational contracts with multiple agents. mimeo.
- Asanuma, B. (1989). Manufacturer-supplier relationships in Japan and the concept of relation-specific skill. *Journal of the Japanese and international economies*, 3(1):1–30.
- Bajari, P., McMillan, R., and Tadelis, S. (2009). Auctions Versus Negotiations in Procurement: An Empirical Analysis. *Journal of Law, Economics and Organization*, 325:372.399.

<sup>60</sup>Note the similarities with the analysis of Baker et al. (2011) on costly contracting.

<sup>61</sup>To determine the buyer's fall-back position after a deviation, we assume that the suppliers converge to the worst equilibrium for the buyer, i.e. that in which  $e_i = 0$  for all  $i$ .

- Bajari, P. and Tadelis, S. (2001). Incentives versus Transaction Costs: A Theory of Procurement Contracts. *The RAND Journal of Economics*, 32:387–407.
- Baker, G., Gibbons, R., and Murphy, K. J. (1994). Subjective performance measures in optimal incentive contracts. *The Quarterly Journal of Economics*, 109(4):1125–56.
- Baker, G., Gibbons, R., and Murphy, K. J. (2011). Relational adaptation. *Unpublished manuscript, USC Marshall School*.
- Board, S. (2011). Relational contracts and the value of loyalty. *American Economic Review*, 101(7):3349–67.
- Bull, C. (1987). The existence of self-enforcing implicit contracts. *The Quarterly Journal of Economics*, 102(1):147–159.
- Burt, D. N. (1989). Managing suppliers up to speed. *Harvard Business Review*, 67(4):127–135.
- Calzolari, G., Felli, L., Koenen, J., Spagnolo, G., and Stahl, K. (2014). Trust, competition and innovation: Evidence from german car manufacturers.
- Calzolari, G. and Spagnolo, G. (2009). Relational contracts and competitive screening. CEPR Discussion Papers 7434, C.E.P.R. Discussion Papers.
- Chakravarty, S. and MacLeod, W. B. (2009). Contracting in the shadow of the law. *The RAND Journal of Economics*, 40(3):533–557.
- Che, Y.-K. and Gale, I. (2003). Optimal design of research contests. *The American Economic Review*, 93(3):646–671.
- Che, Y.-K. and Hausch, D. B. (1999). Cooperative investments and the value of contracting. *American Economic Review*, pages 125–147.
- Che, Y.-K. and Yoo, S.-W. (2001). Optimal incentives for teams. *American Economic Review*, pages 525–541.
- Chung, T.-Y. (1991). Incomplete contracts, specific investments, and risk sharing. *The Review of Economic Studies*, 58(5):1031–1042.
- Clark, K. B. (1989). Project scope and project performance: the effect of parts strategy and supplier involvement on product development. *Management science*, 35(10):1247–1263.
- Corts, K. S. (2012). The interaction of implicit and explicit contracts in construction and procurement contracting. *Journal of Law, Economics, and Organization*, 28(3):550–568.
- Dyer, J. H. (1996). How Chrysler created an American keiretsu. *Harvard Business Review*.
- Edlin, A. S. and Reichelstein, S. J. (1996). Holdups, standard breach remedies, and optimal investment. *American Economic Review*.

- Fudenberg, D., Levine, D. I., and Maskin, E. (1994). The folk theorem with imperfect public information. *Econometrica*, 62(5):997–1039.
- Fullerton, R. L. and McAfee, R. P. (1999). Auctioning entry into tournaments. *Journal of Political Economy*, 107(3):573–605.
- Ganuza, J.-J. (2007). Competition and cost overruns in procurement. *The Journal of Industrial Economics*, 55(4):633–660.
- Klein, B., Crawford, R. G., and Alchian, A. A. (1978). Vertical integration, appropriable rents, and the competitive contracting process. *Journal of Law and Economics*, 21:297.
- Kvaløy, O. and Olsen, T. E. (2009). Endogenous verifiability and relational contracting. *The American Economic Review*, pages 2193–2208.
- Laffont, J.-J. and Tirole, J. (1993). *A theory of incentives in procurement and regulation*. MIT press.
- Legros, P. and Newman, A. F. (2008). Competing for ownership. *Journal of the European Economic Association*, 6(6):1279–1308.
- Levin, J. (2003). Relational incentive contracts. *American Economic Review*, 93(3):835–857.
- Loertscher, S. and Riordan, M. H. (2014). Outsourcing, vertical integration, and cost reduction.
- MacLeod, W. B. and Malcomson, J. M. (1989). Implicit contracts, incentive compatibility, and involuntary unemployment. *Econometrica: Journal of the Econometric Society*, pages 447–480.
- Malcomson, J. M. (2012). Relational incentive contracts. *Handbook of Organizational Economics* eds. Robert Gibbons and John Roberts, pages 1014–1065.
- McMillan, J. (1990). Managing Suppliers: Incentive Systems in Japanese and US Industry. *California Management Review*, 32(4).
- McMillan, J. (1994). Reorganizing Vertical Supply Relationships. *Trends in business organization: Do participation and cooperation increase competitiveness?*, pages 203–222.
- Milgrom, P. and Roberts, J. (1990). The economics of modern manufacturing: Technology, strategy, and organization. *The American Economic Review*, pages 511–528.
- Moldovanu, B. and Sela, A. (2001). The optimal allocation of prizes in contests. *American Economic Review*, pages 542–558.
- Myerson, R. B. (1981). Optimal auction design. *Mathematics of operations research*, 6(1):58–73.
- Roberts, J. (2004). *The Modern Firm: Organizational Design for Performance and Growth*. Oxford University Press.

- Rogerson, W. P. (1984). Efficient reliance and damage measures for breach of contract. *RAND Journal of Economics*, 15(1):39–53.
- Shavell, S. (1984). The design of contracts and remedies for breach. *The Quarterly Journal of Economics*, 99(1):121–148.
- Tan, G. (1992). Entry and r & d in procurement contracting. *Journal of Economic Theory*, 58(1):41–60.
- Taylor, C. R. (1995). Digging for golden carrots: an analysis of research tournaments. *The American Economic Review*, pages 872–890.
- Taylor, C. R. and Wiggins, S. N. (1997). Competition or compensation: Supplier incentives under the american and japanese subcontracting systems. *The American Economic Review*, pages 598–618.
- Tirole, J. (2009). Cognition and incomplete contracts. *The American Economic Review*, 99(1):265–294.
- Transportation-Research-Board (2013). Legal aspects of performance-based specifications for highway construction and maintenance contracts. Technical report, National Cooperative Highway Research Program (NCHRP) - Legal Research Digest 61.
- Tunca, T. I. and Zenios, S. A. (2006). Supply auctions and relational contracts for procurement. *Manufacturing & Service Operations Management*, 8(1):43–67.
- Van Biesebroeck, J. (2007). Complementarities in automobile production. *Journal of Applied Econometrics*, 22(7):1315–1345.
- Williamson, O. E. (1975). Markets and hierarchies. *New York*, pages 26–30.
- Womack, J. P., Jones, D. T., and Roos, D. (2007). *The Machine that changed the world: The story of lean production*. Simon and Schuster.